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Gopalan et al.

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(54) **DEVICE AND METHOD FOR ADAPTIVE RATE MULTIMEDIA COMMUNICATIONS ON A WIRELESS NETWORK**

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CPC **H04W 28/0236** (2013.01); **H04L 47/263** (2013.01); **H04L 47/30** (2013.01); **H04W 28/14** (2013.01)

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See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,359,883 B1 * 3/2002 Lechleider 370/389
6,438,702 B1 8/2002 Hodge
6,445,679 B1 9/2002 Taniguchi et al.
6,894,974 B1 5/2005 Aweva et al.
7,058,431 B2 6/2006 Sasaki
7,120,090 B2 10/2006 Smith et al.
7,225,267 B2 5/2007 Key et al.
7,251,241 B1 7/2007 Jagadeesan et al.

(Continued)

FOREIGN PATENT DOCUMENTS

CN 102595093 A 7/2012
WO WO-0178489 A2 10/2001

OTHER PUBLICATIONS

Kanakia H., et al., "An Adaptive Congestion Control Scheme for Real Time Packet Video Transport", IEEE / ACM Transactions on Networking, IEEE / ACM, New York, NY, US, vol. 3, No. 6, Dec. 1, 1995, pp. 671-682, XP000544171, ISSN: 1063-6692.

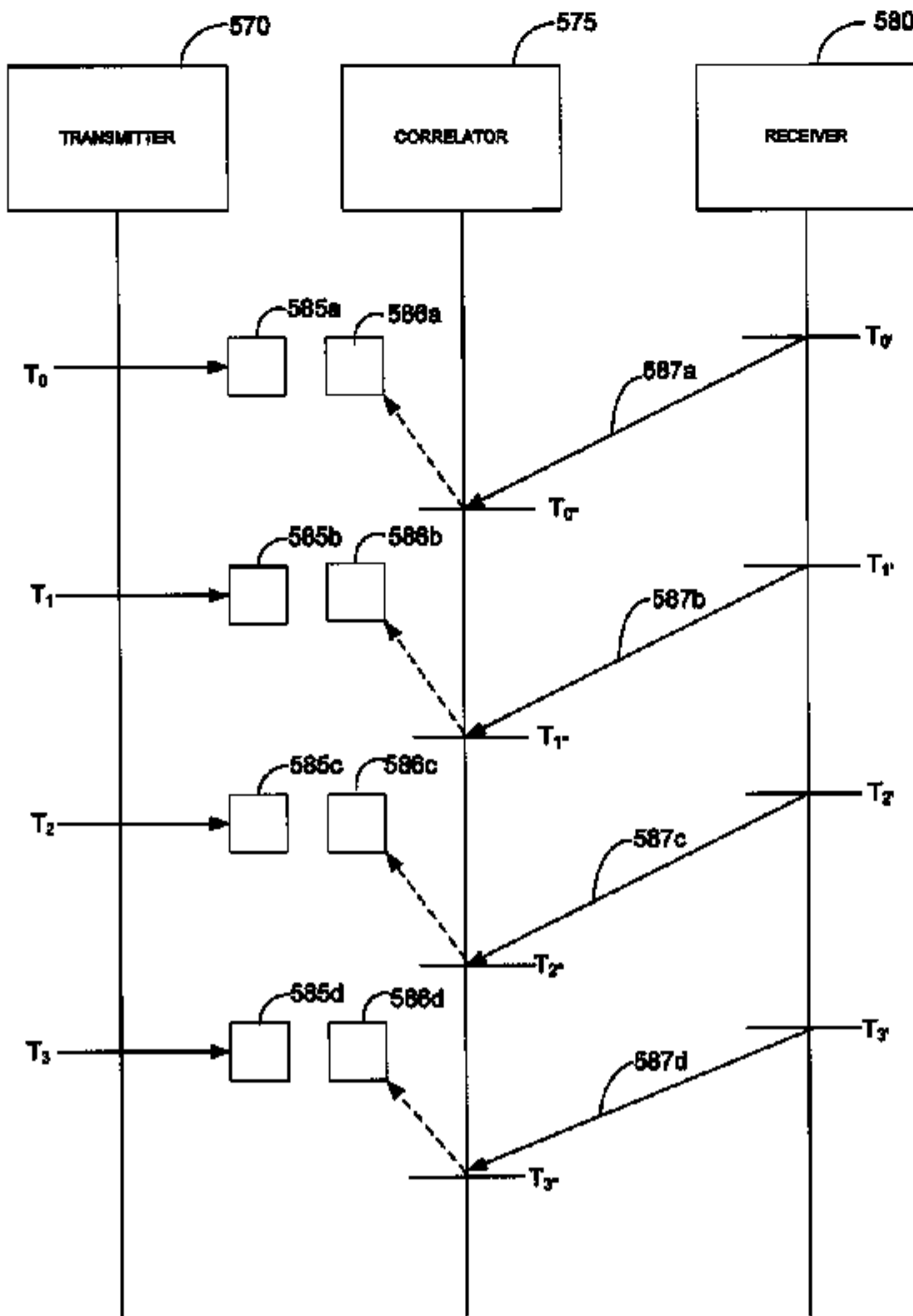
(Continued)

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(57) **ABSTRACT**

Methods, apparatus, and computer readable media determine a transmission rate. In some aspects, a method includes determining, via an electronic device, an amount of data buffered in a network, determining a sustainable throughput of the network; and determining a transmission rate based at least in part on the sustainable throughput and the amount of data buffered.

27 Claims, 23 Drawing Sheets



(56)

References Cited

U.S. PATENT DOCUMENTS

7,581,019 B1 8/2009 Amir et al.
7,787,438 B2 8/2010 Dowse
7,962,637 B2 6/2011 Su et al.
7,974,233 B2 7/2011 Banerjee
7,975,063 B2 7/2011 Lefebvre
8,009,687 B2 8/2011 Chew et al.
8,166,186 B2 4/2012 Inokuchi
8,175,167 B2 5/2012 Bouton et al.
8,279,968 B2 10/2012 Lindblom et al.
8,281,356 B2 10/2012 Ohno et al.
8,306,058 B2 11/2012 Bai et al.
8,774,233 B1 7/2014 Loc et al.
2002/0040396 A1 4/2002 Yoshihara et al.
2002/0129290 A1 9/2002 Couillard
2005/0030887 A1 2/2005 Jacobsen et al.
2005/0100100 A1 5/2005 Unger et al.
2007/0053446 A1 3/2007 Spilo
2007/0091815 A1 4/2007 Tinnakornsisuphap et al.
2007/0091816 A1 4/2007 Lee et al.
2007/0260850 A1 11/2007 Kameyama et al.
2008/0084925 A1 4/2008 Rozen et al.
2008/0101466 A1 5/2008 Swenson et al.
2008/0186849 A1 8/2008 Kampmann et al.
2008/0192710 A1 8/2008 Balachandran et al.
2008/0212599 A1 9/2008 Chen et al.
2008/0260042 A1 10/2008 Shah et al.
2009/0034610 A1 2/2009 Lee et al.
2009/0046595 A1 2/2009 Clark
2009/0154353 A1 6/2009 Loiacono et al.
2009/0180379 A1 7/2009 Leung et al.
2010/0082834 A1 4/2010 Joung et al.

2010/0098047 A1 4/2010 Zhou et al.
2010/0124275 A1 5/2010 Yeh et al.
2010/0135332 A1 6/2010 Siemens et al.
2010/0195548 A1 8/2010 Navda et al.
2011/0060792 A1 3/2011 Ebersviller
2011/0228845 A1 9/2011 Banerjee
2011/0276710 A1 11/2011 Mighani et al.
2011/0286560 A1 11/2011 Pignatelli
2011/0307604 A1 12/2011 Wakuda
2012/0005361 A1 1/2012 Knittle
2012/0039332 A1 2/2012 Jackowski et al.
2012/0120254 A1* 5/2012 Tan et al. 348/184
2012/0120813 A1 5/2012 Johansson et al.
2012/0151009 A1 6/2012 Bouazizi et al.
2012/0230390 A1* 9/2012 Akkor 375/240.02
2012/0307886 A1 12/2012 Agarwal et al.
2012/0311168 A1 12/2012 Dougan et al.
2012/0314761 A1 12/2012 Melnyk et al.
2012/0327789 A1 12/2012 Grenier et al.
2013/0010858 A1 1/2013 Kishigami et al.
2013/0111060 A1* 5/2013 Nilsson et al. 709/231
2014/0056145 A1 2/2014 Gopalan et al.
2014/0056162 A1 2/2014 Gopalan et al.
2014/0059167 A1 2/2014 Gopalan et al.

OTHER PUBLICATIONS

Bridges P.G., et al., "Cholla: A Framework for Composing and Coordinating Adaptations in Networked Systems", IEEE Transactions on Computers, IEEE Service Center, Los Alamitos, CA, US, vol. 58, No. 11, Nov. 1, 2009, pp. 1456-1469, XP011268282, ISSN: 0018-9340. International Search Report and Written Opinion—PCT/US2013/056655—ISA/EPO—Mar. 27, 2014.

* cited by examiner

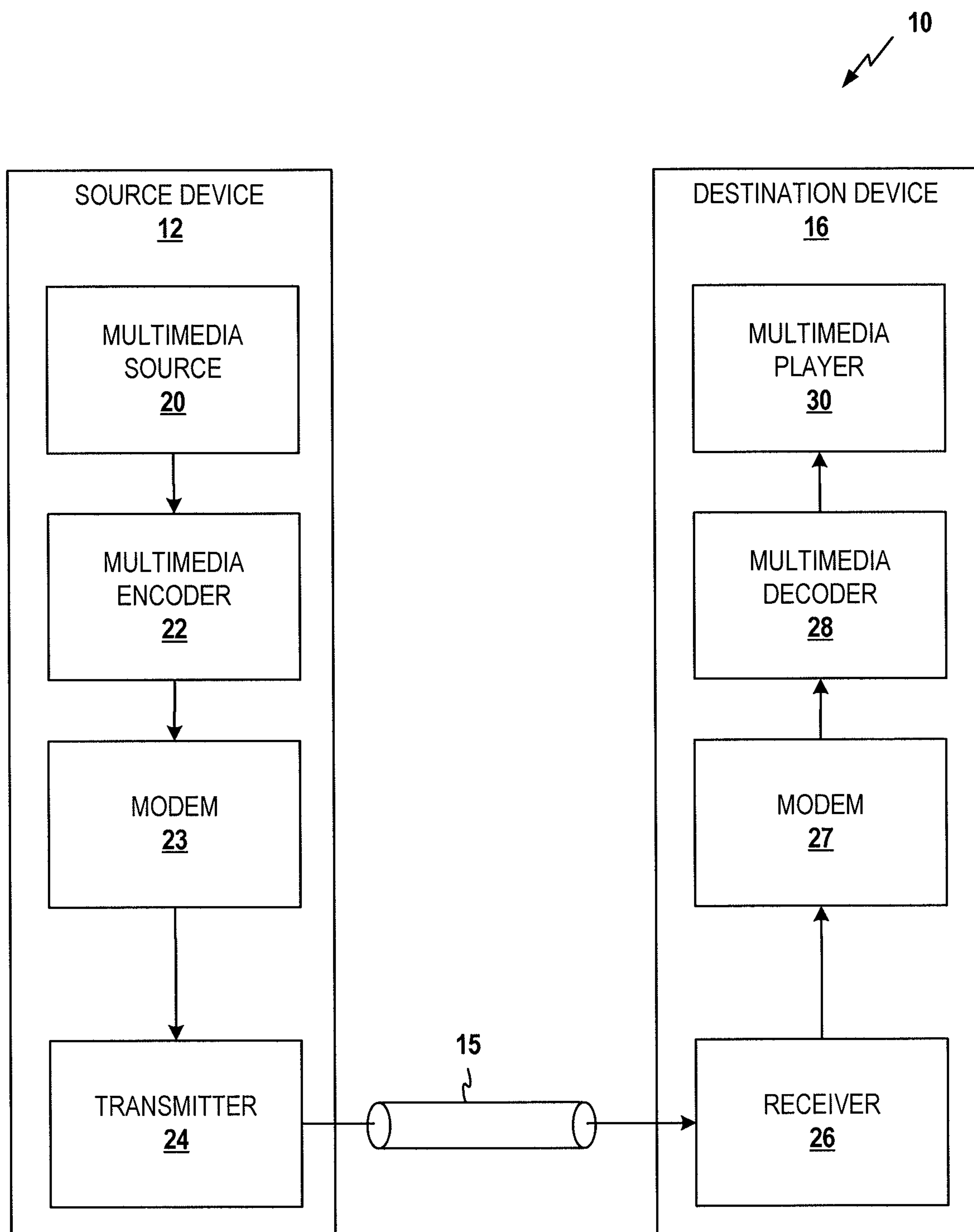


FIG. 1

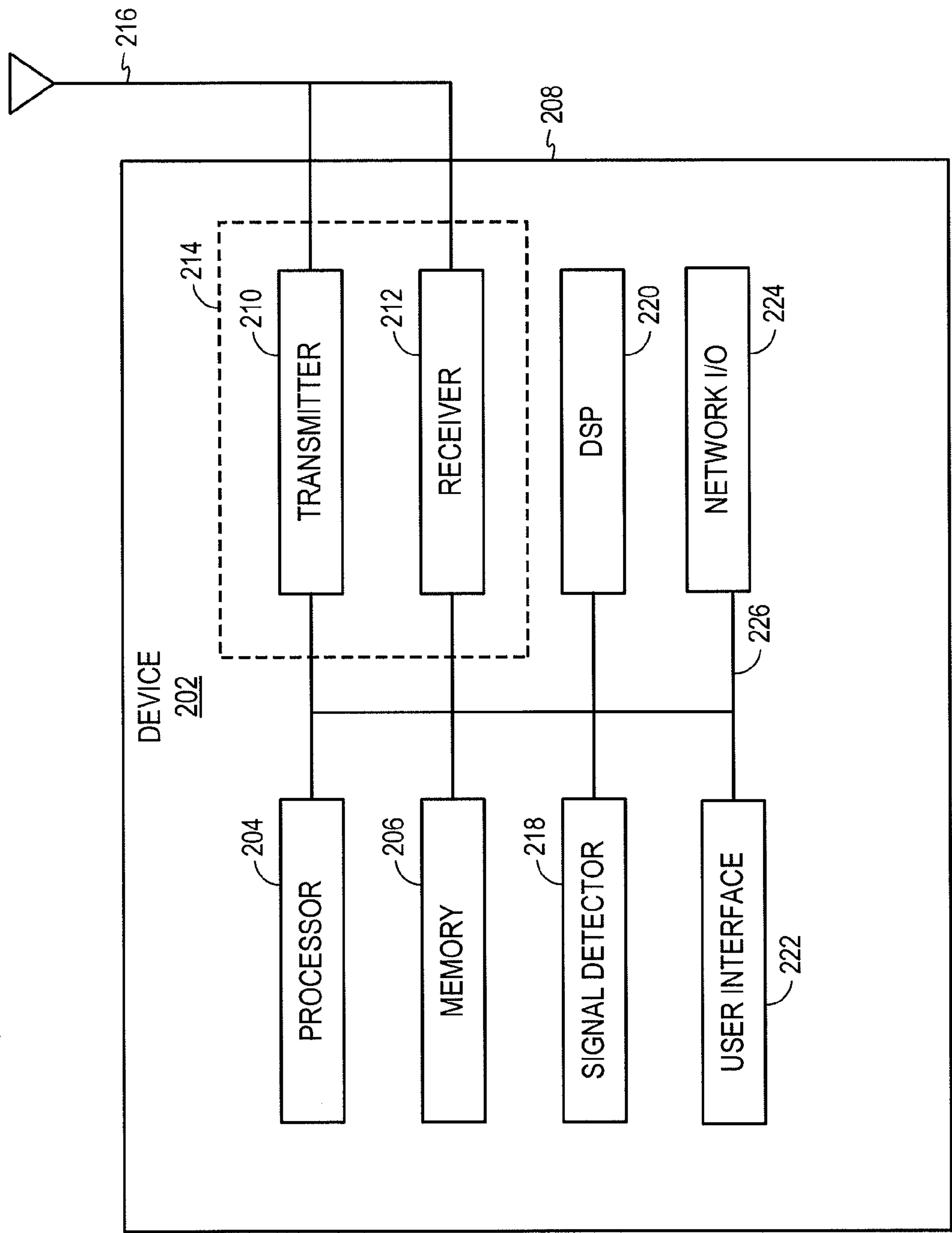
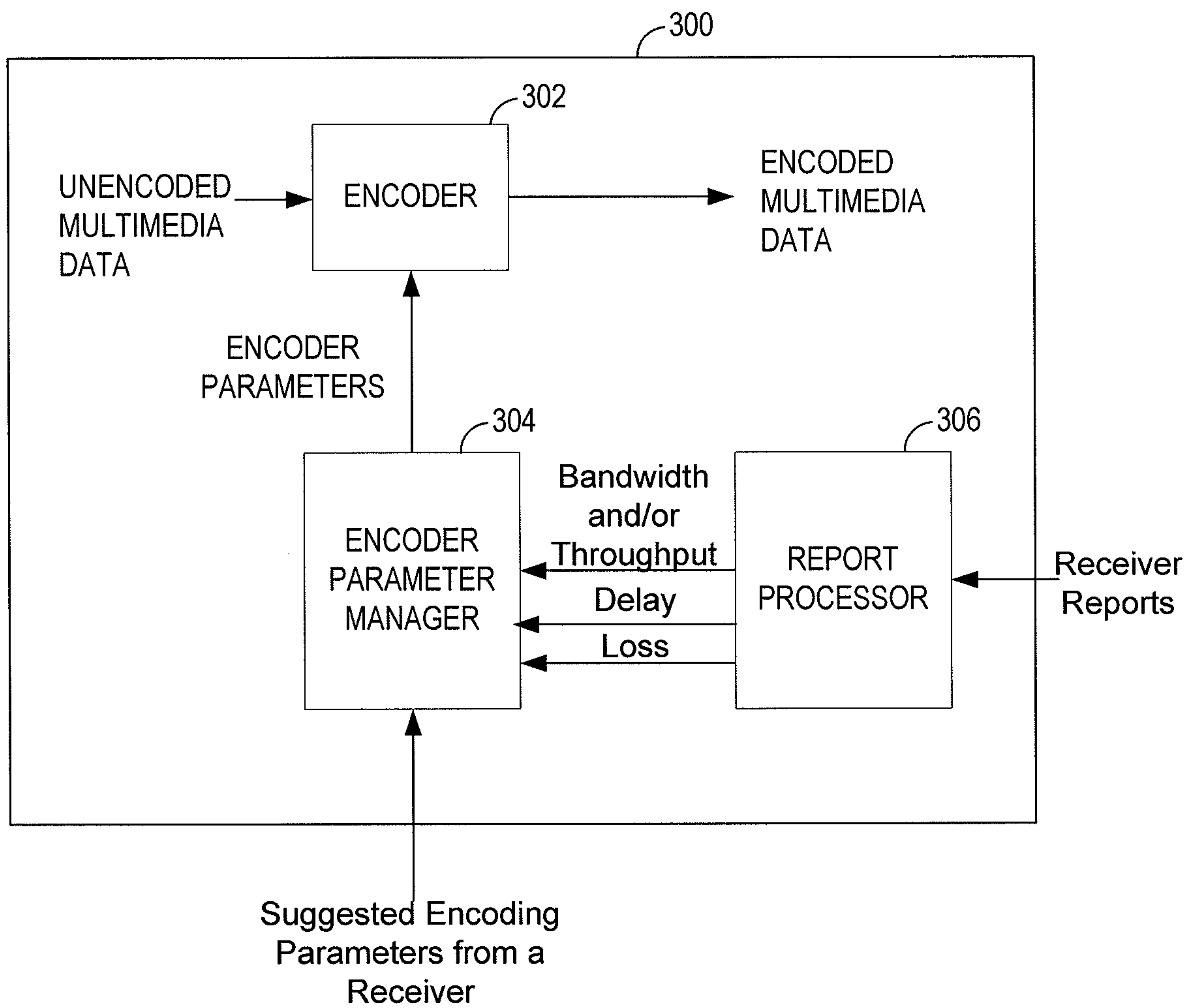
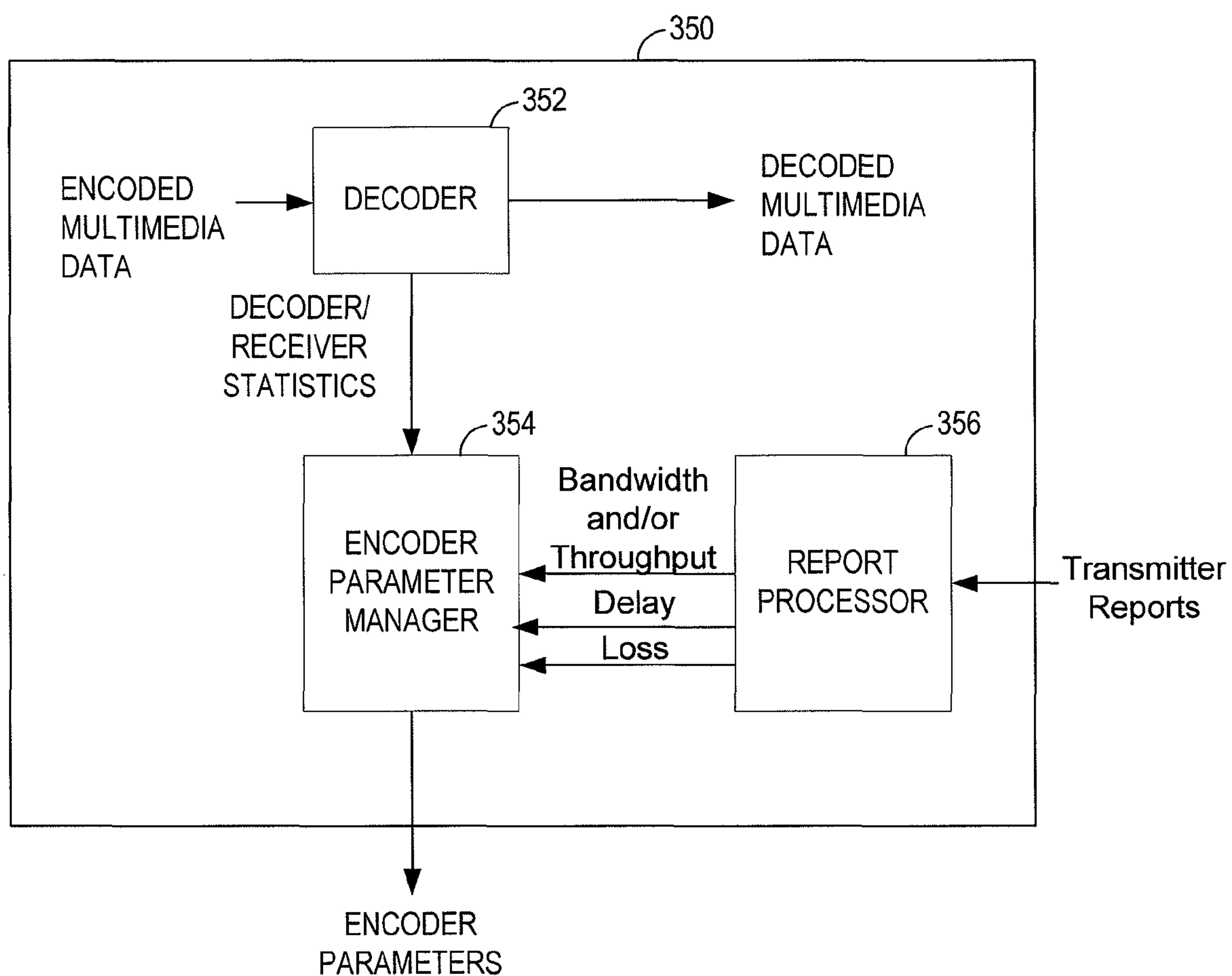


FIG. 2

**FIG. 3A**

**FIG. 3B**

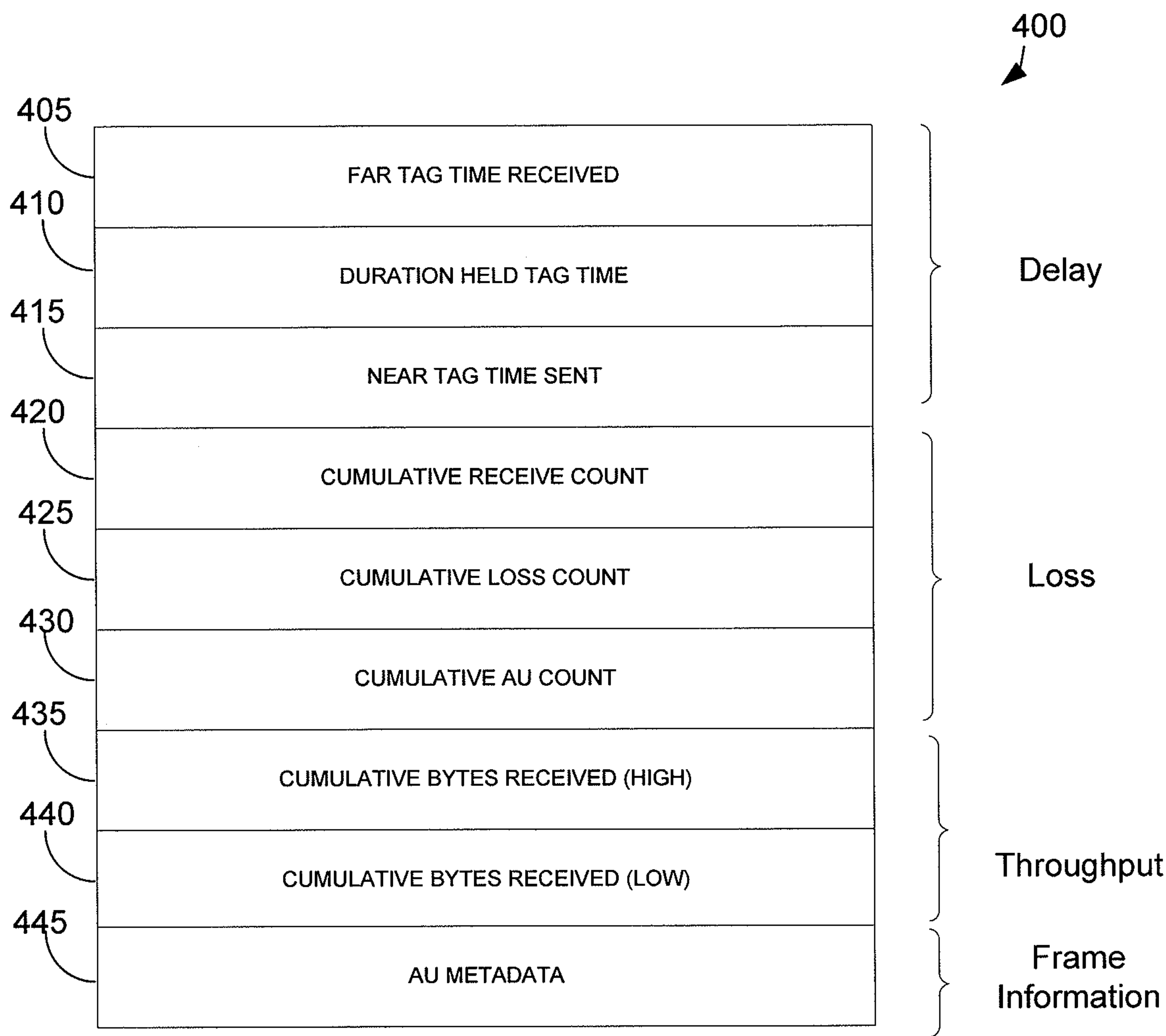
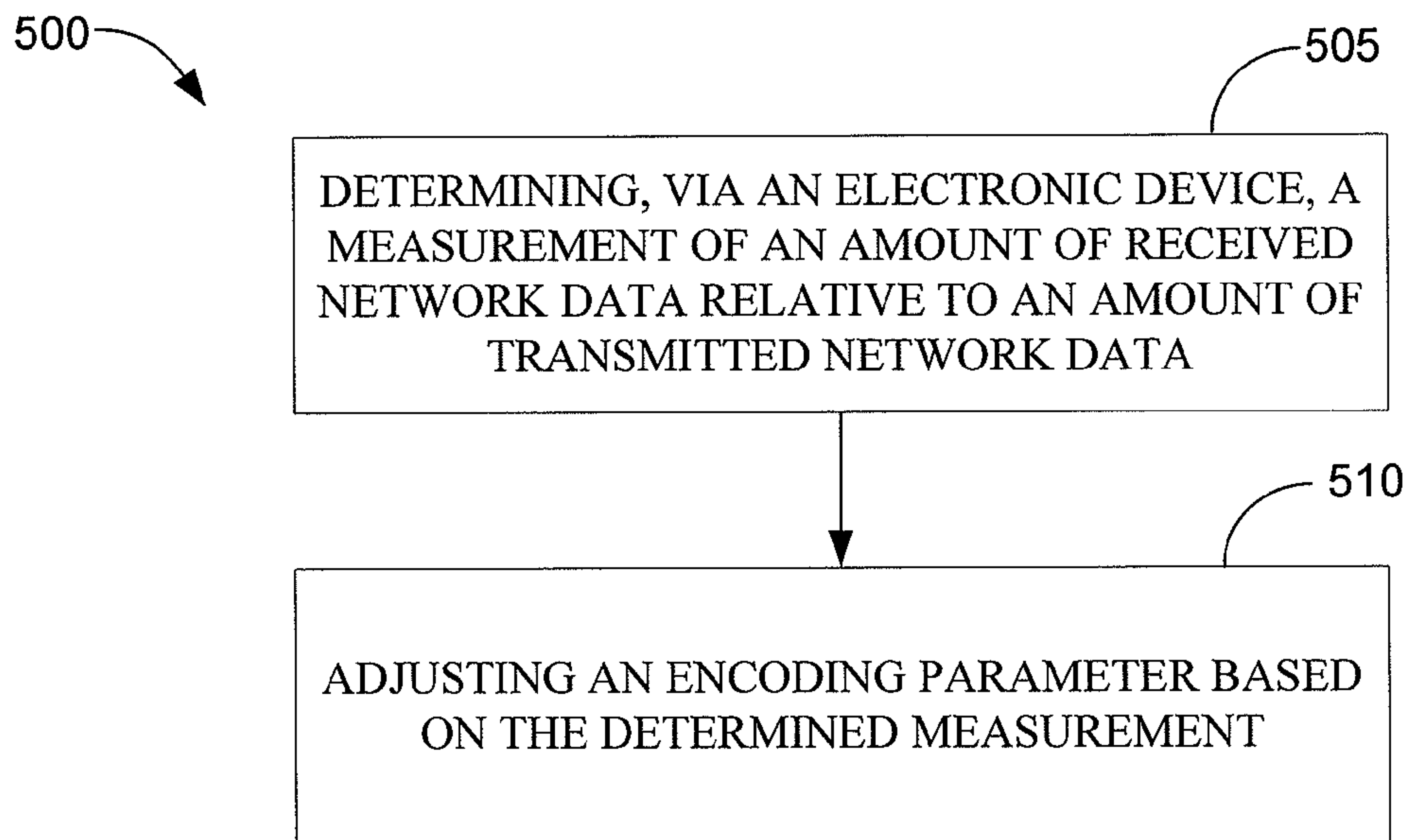
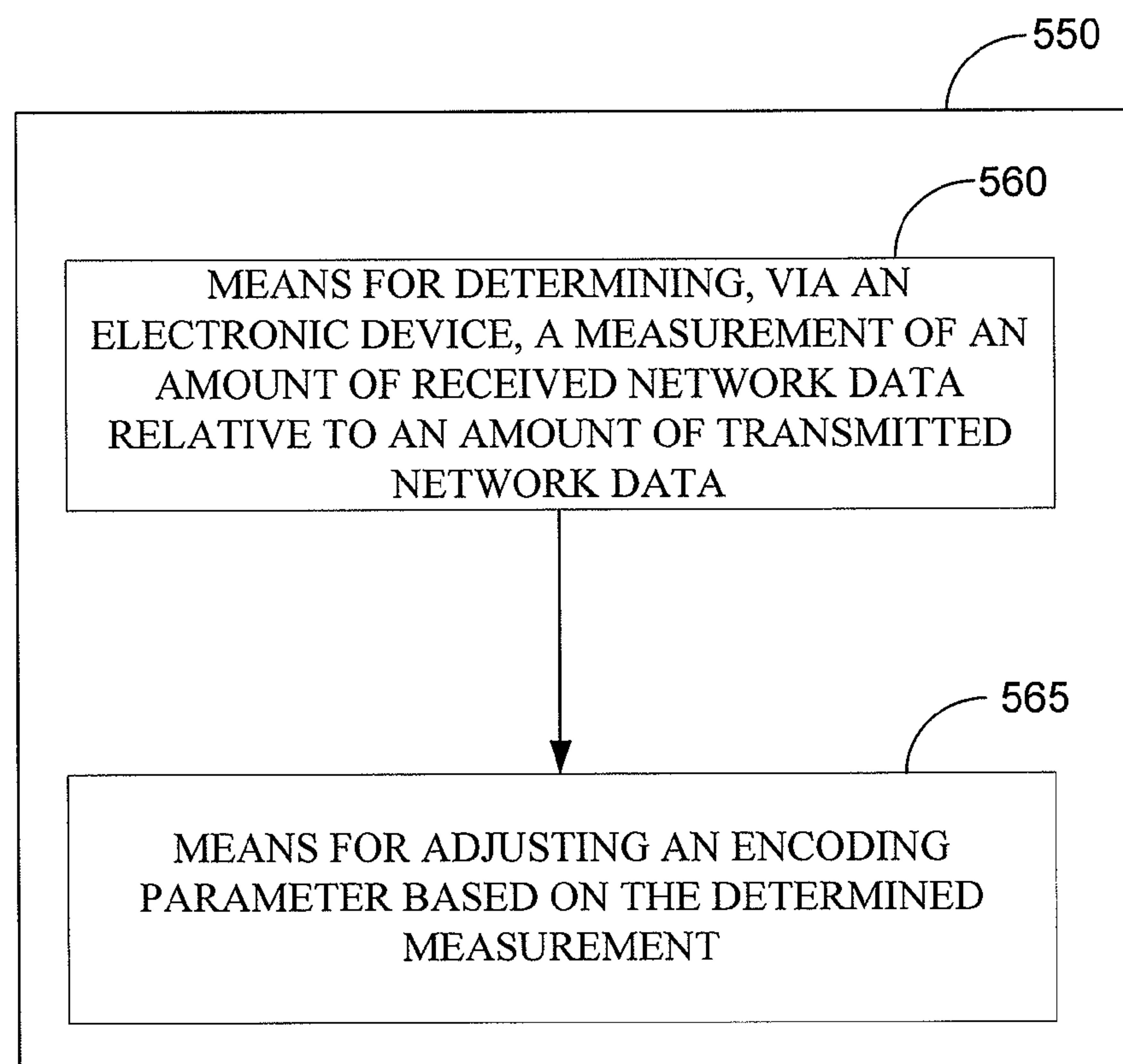


FIG. 4

*FIG. 5A**FIG. 5B*

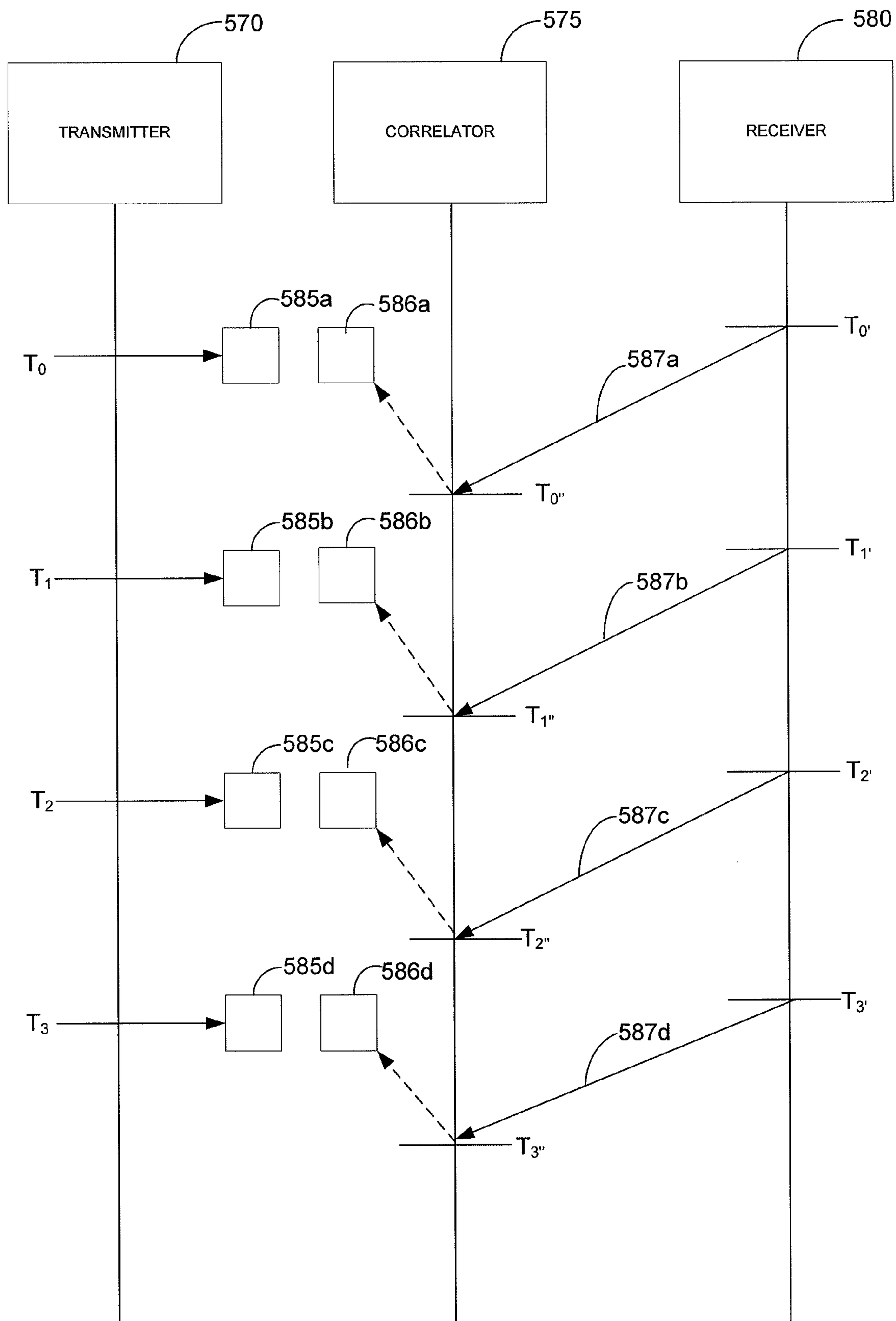
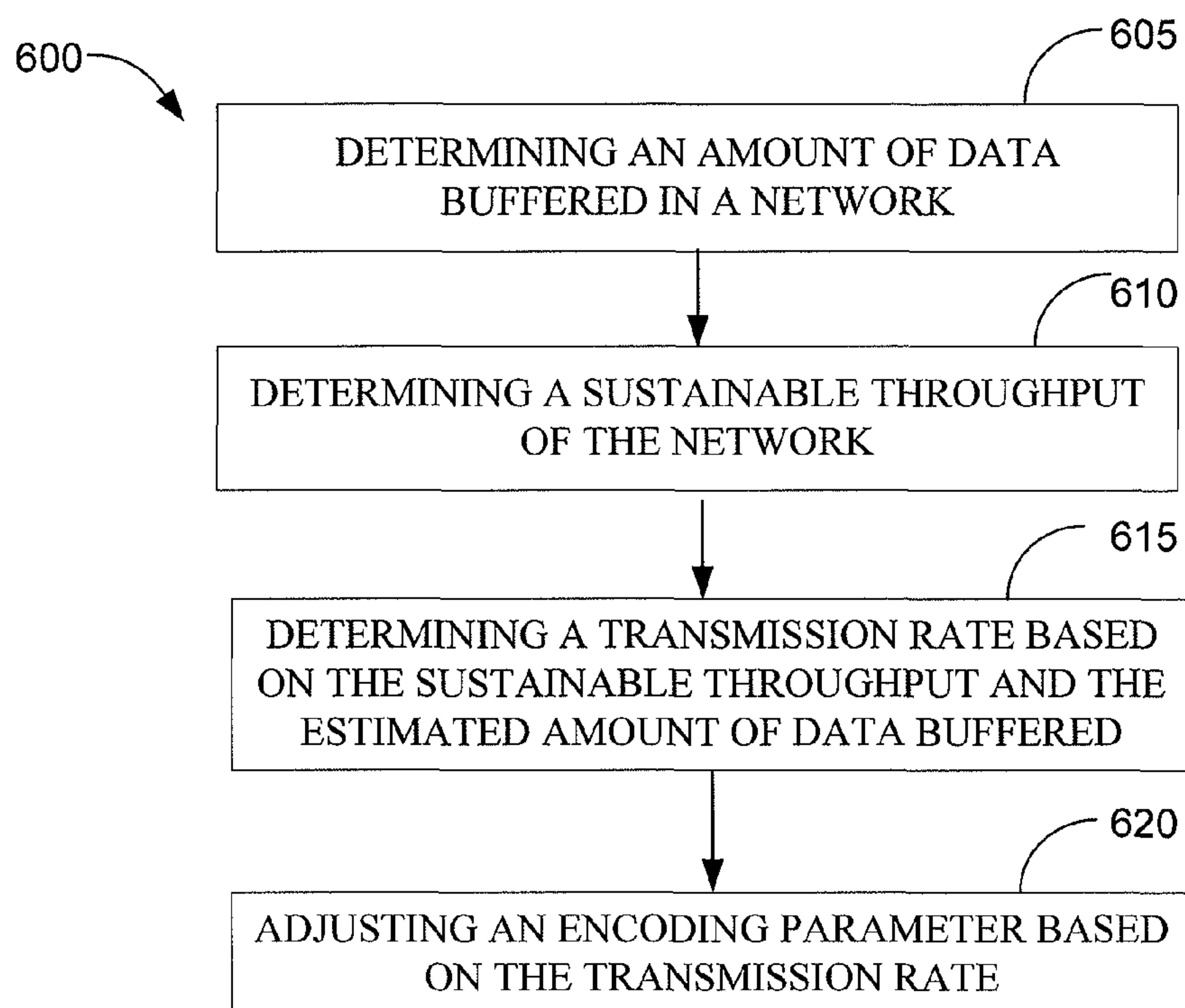
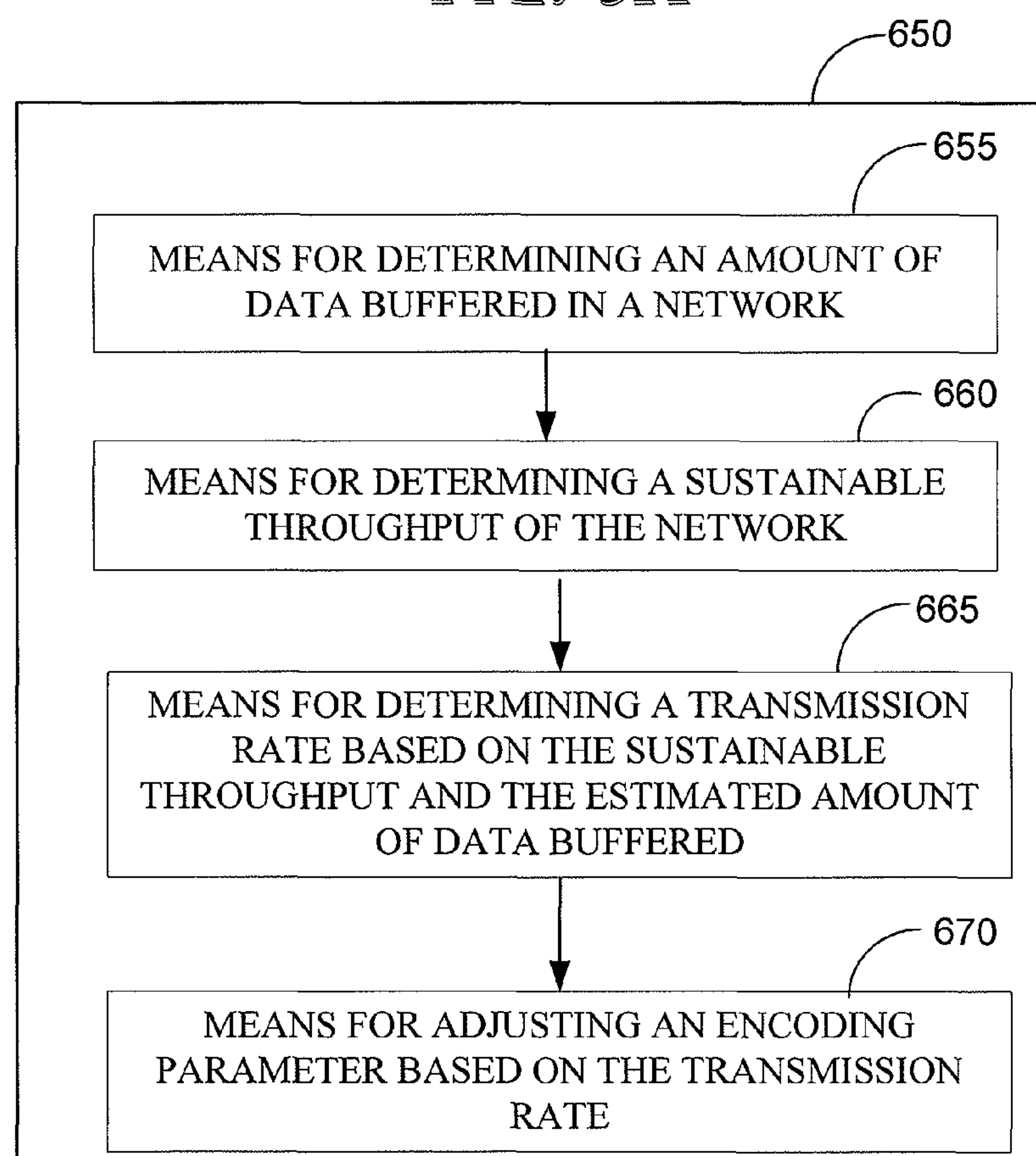


FIG. 5C

*FIG. 6A**FIG. 6B*

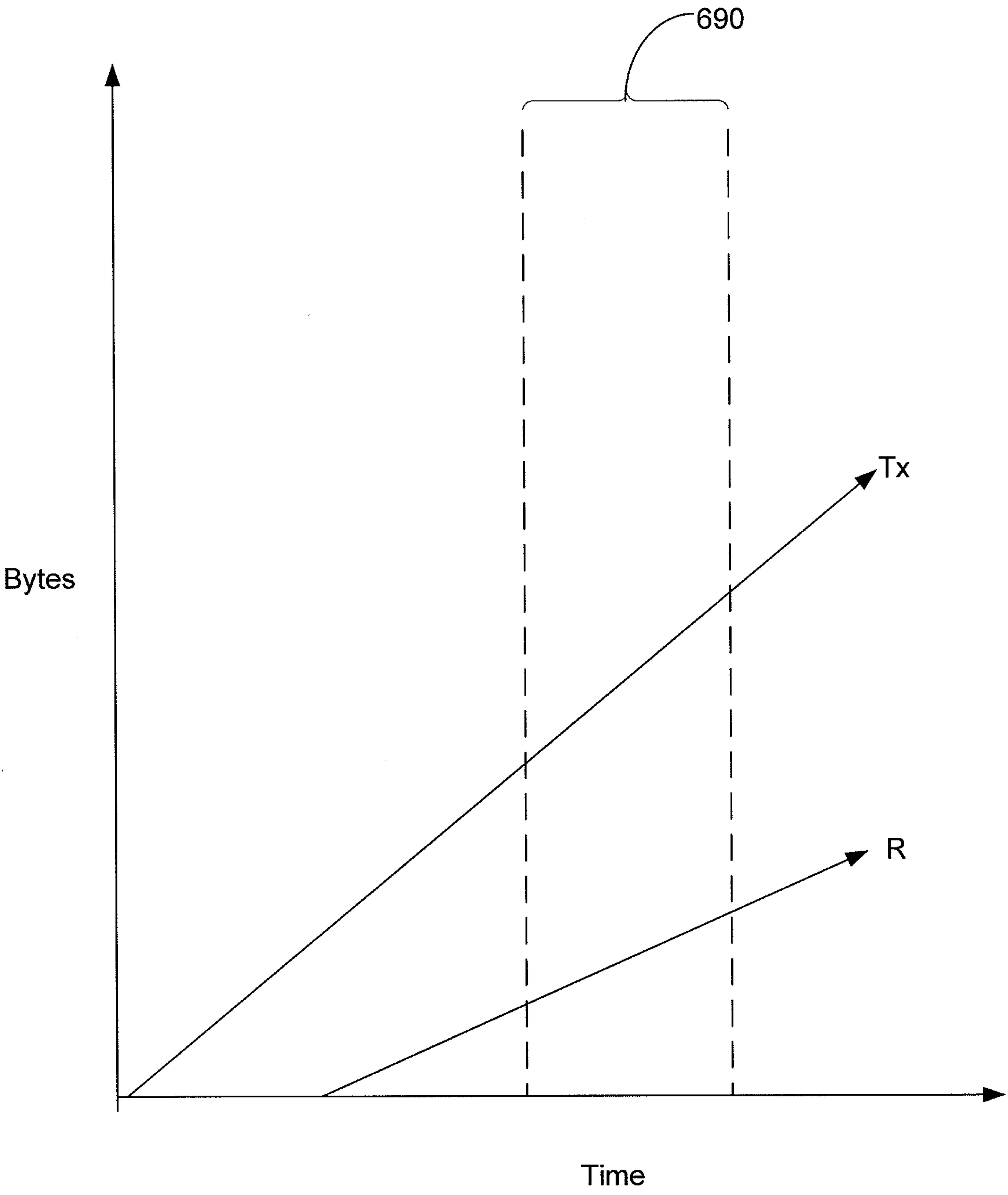


FIG. 6C

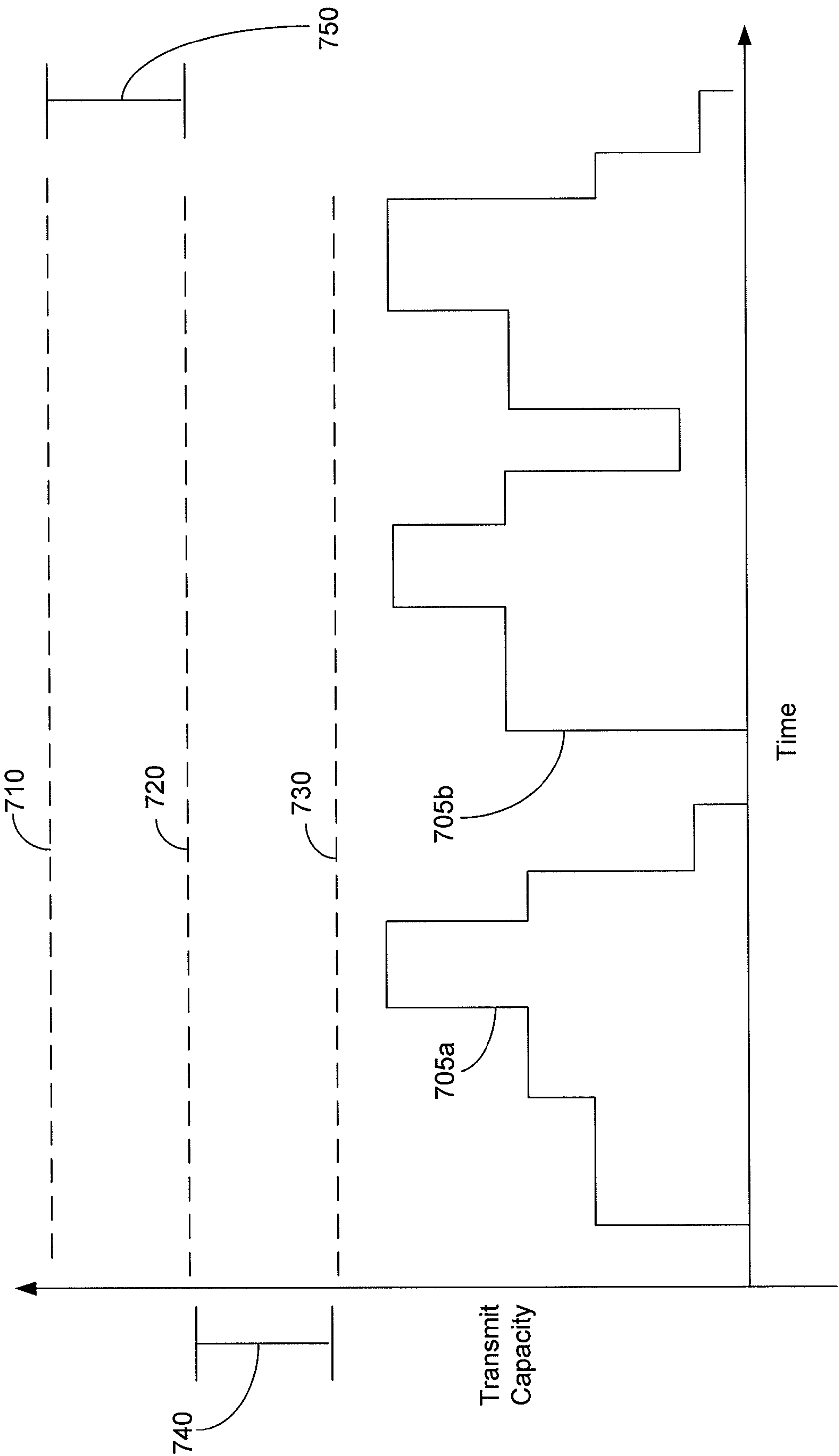
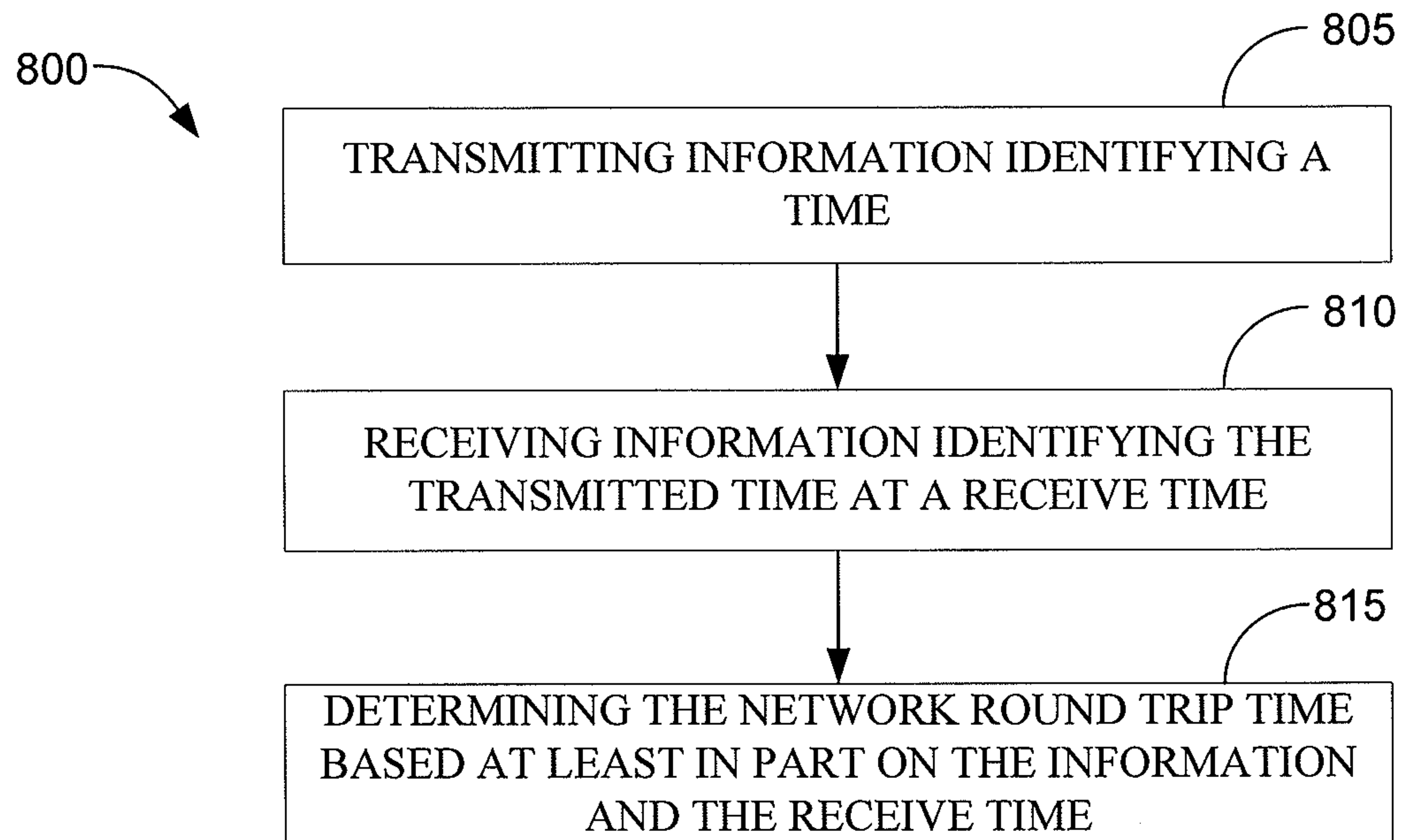
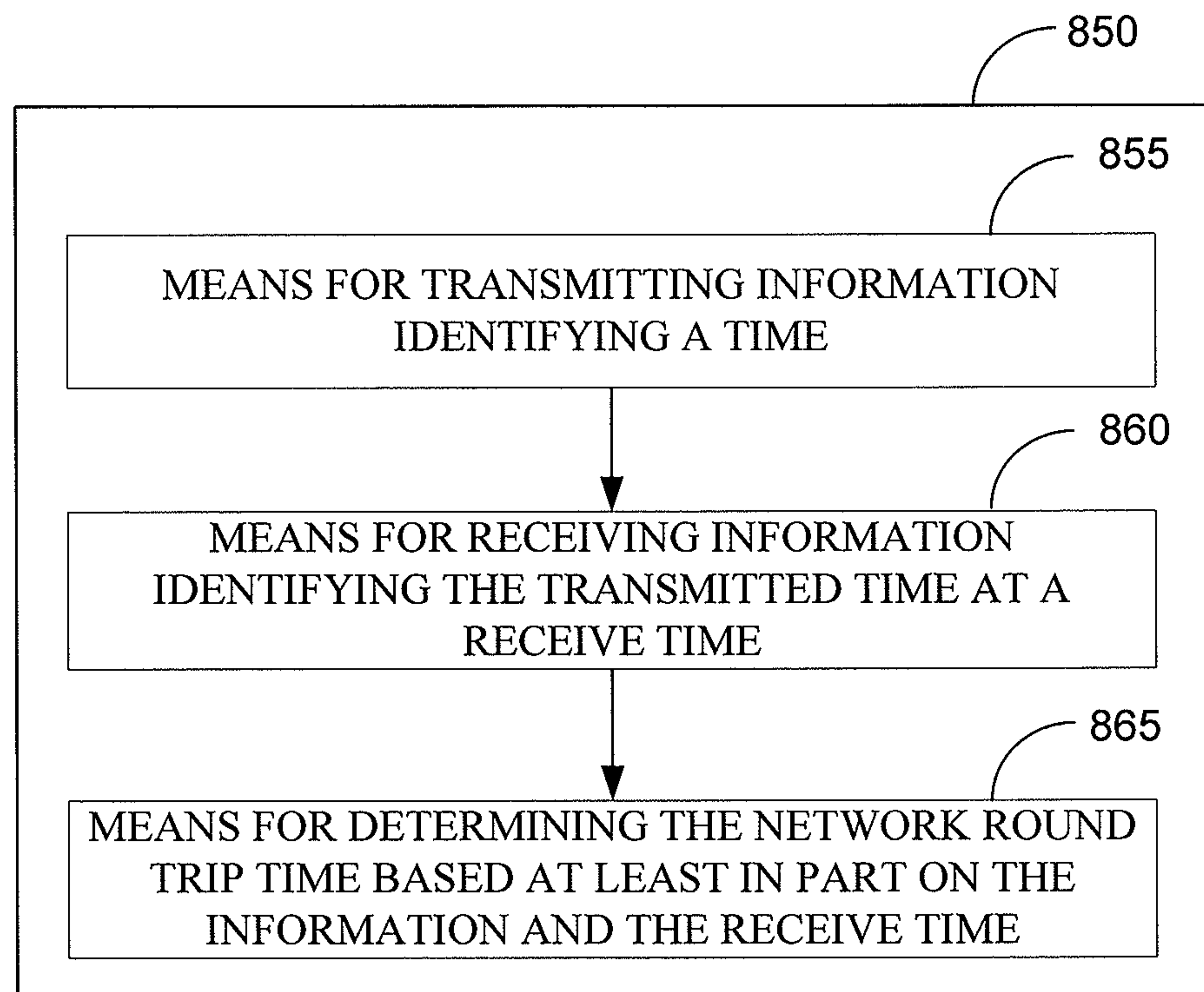


FIG. 7

*FIG. 8A**FIG. 8B*

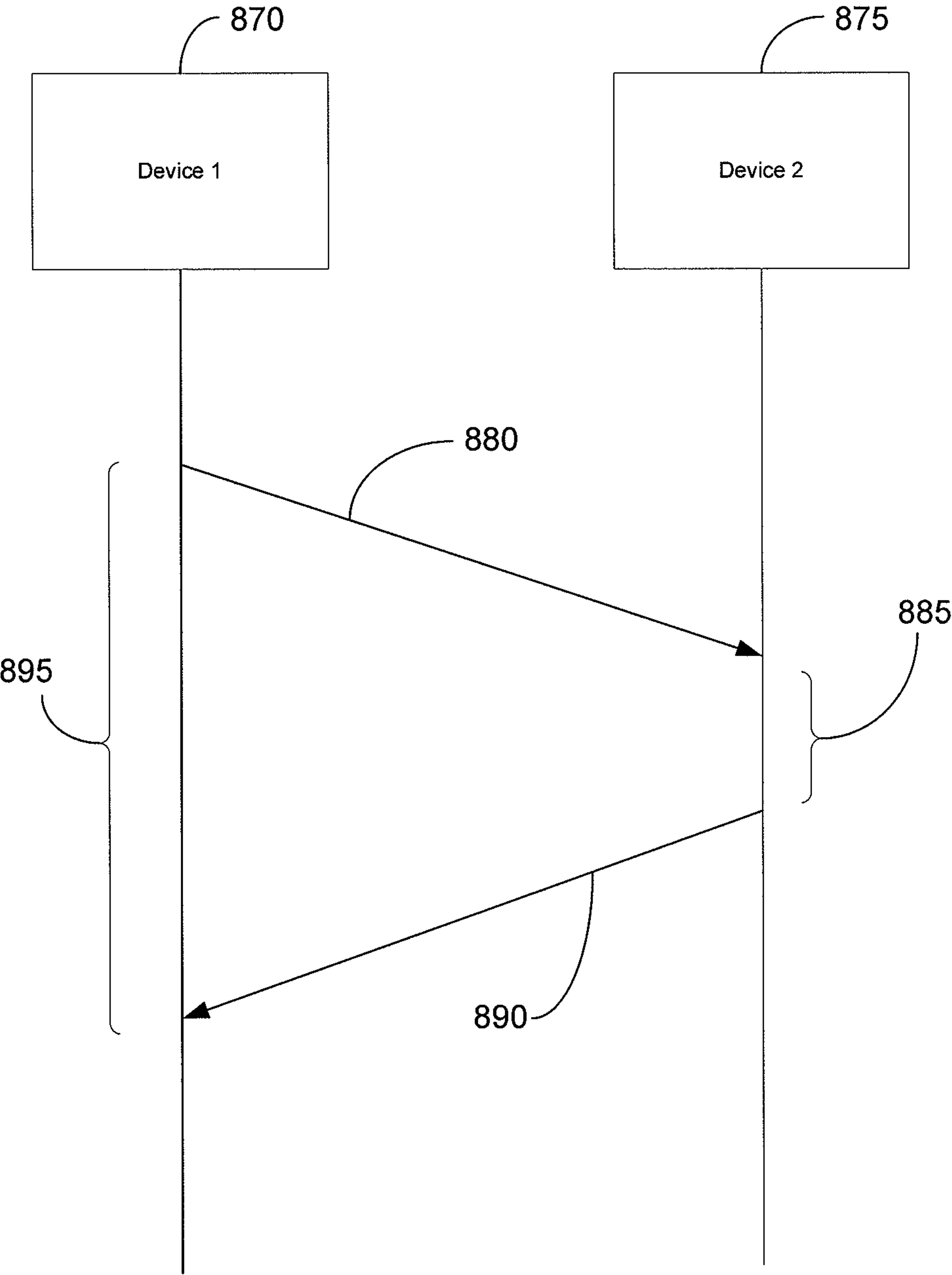
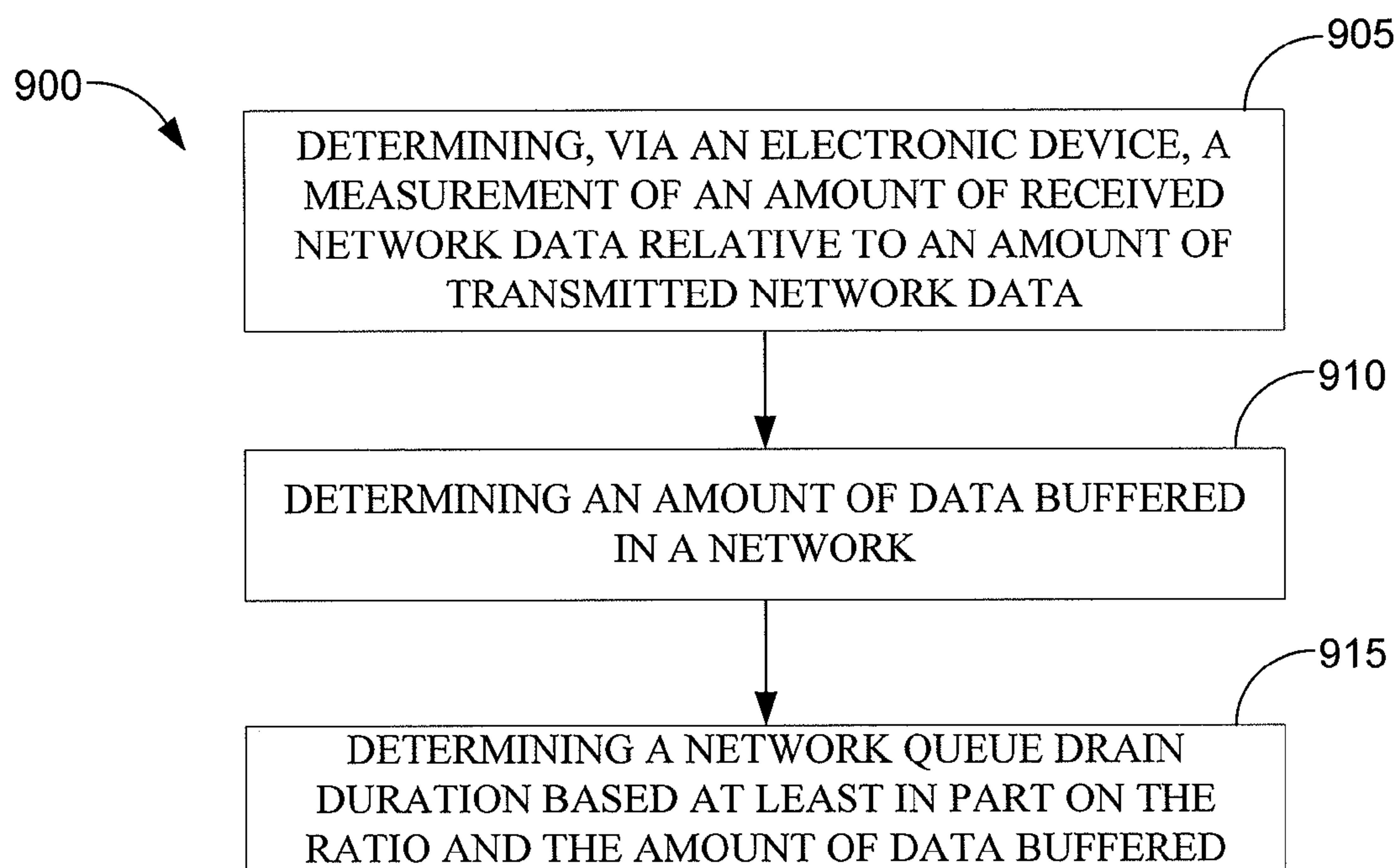
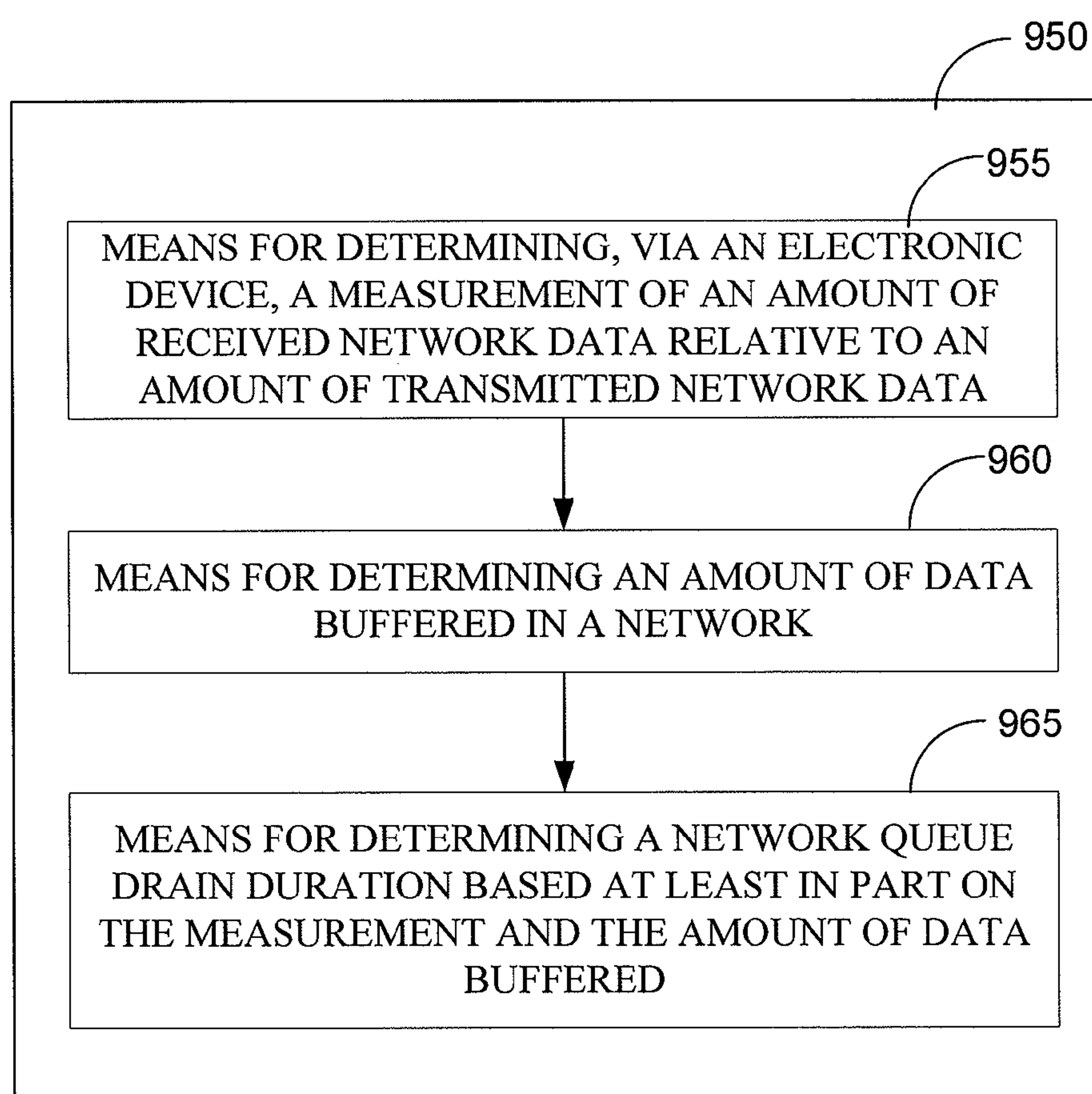


FIG. 8C

*FIG. 9A**FIG. 9B*

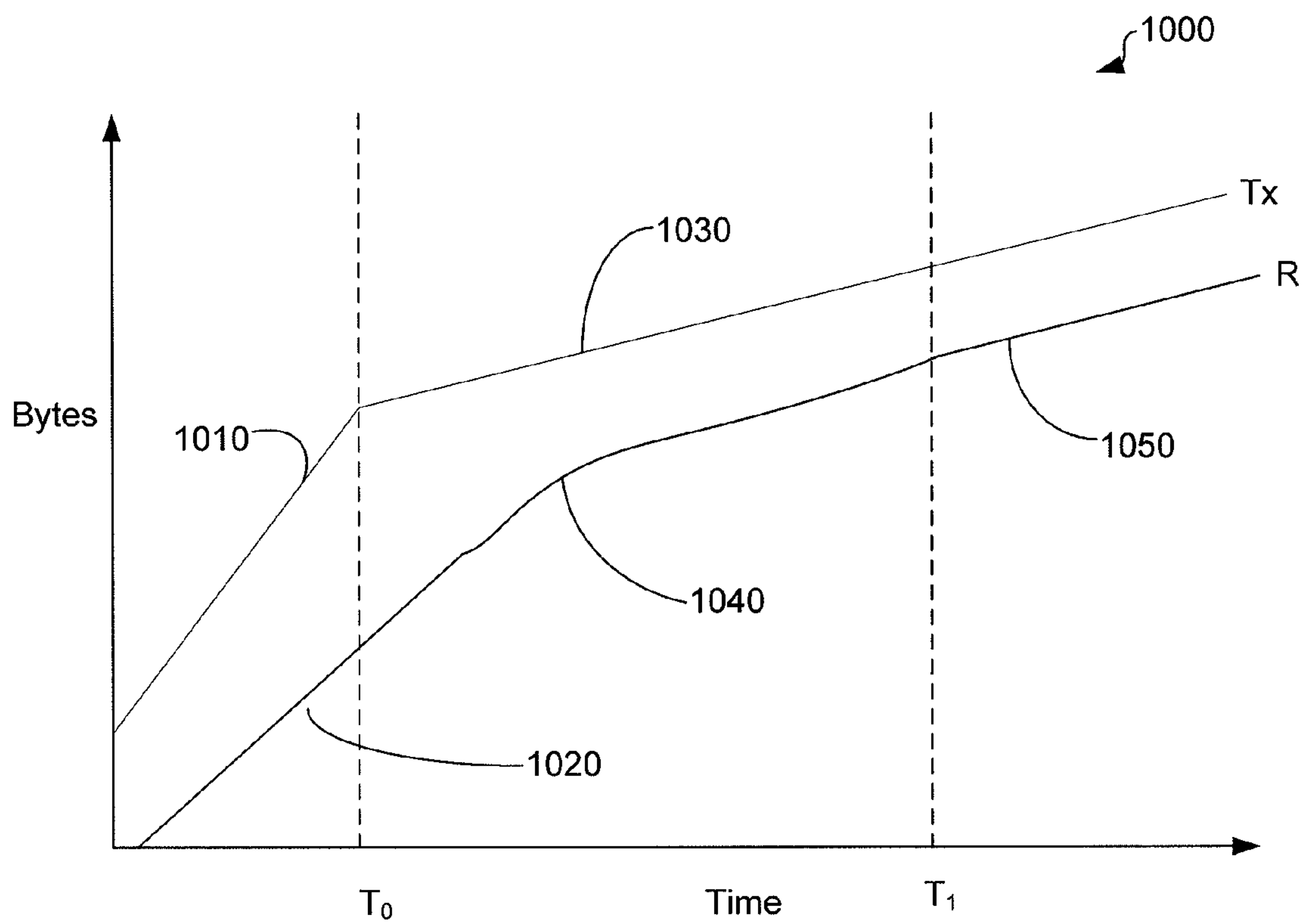


FIG. 10A

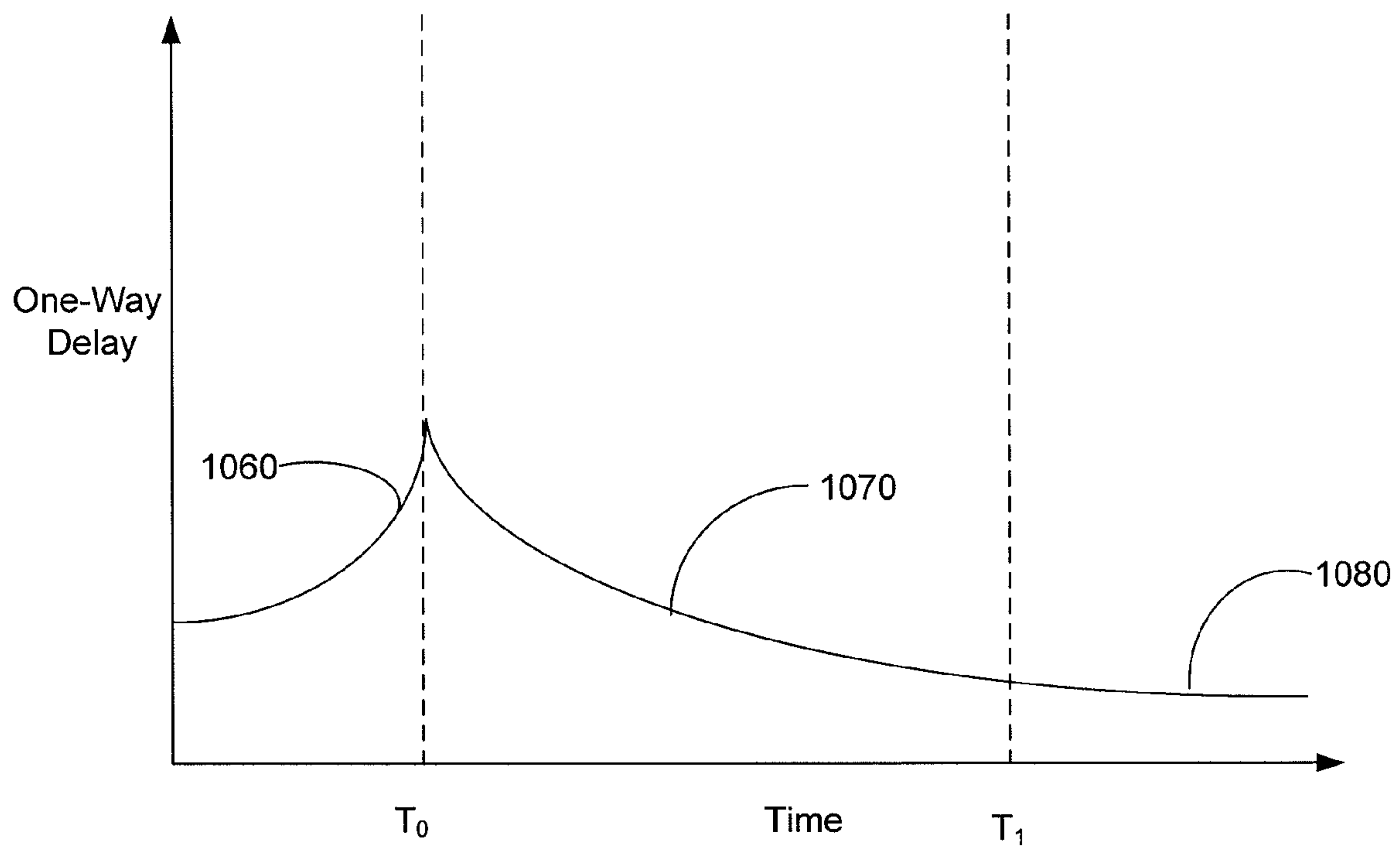
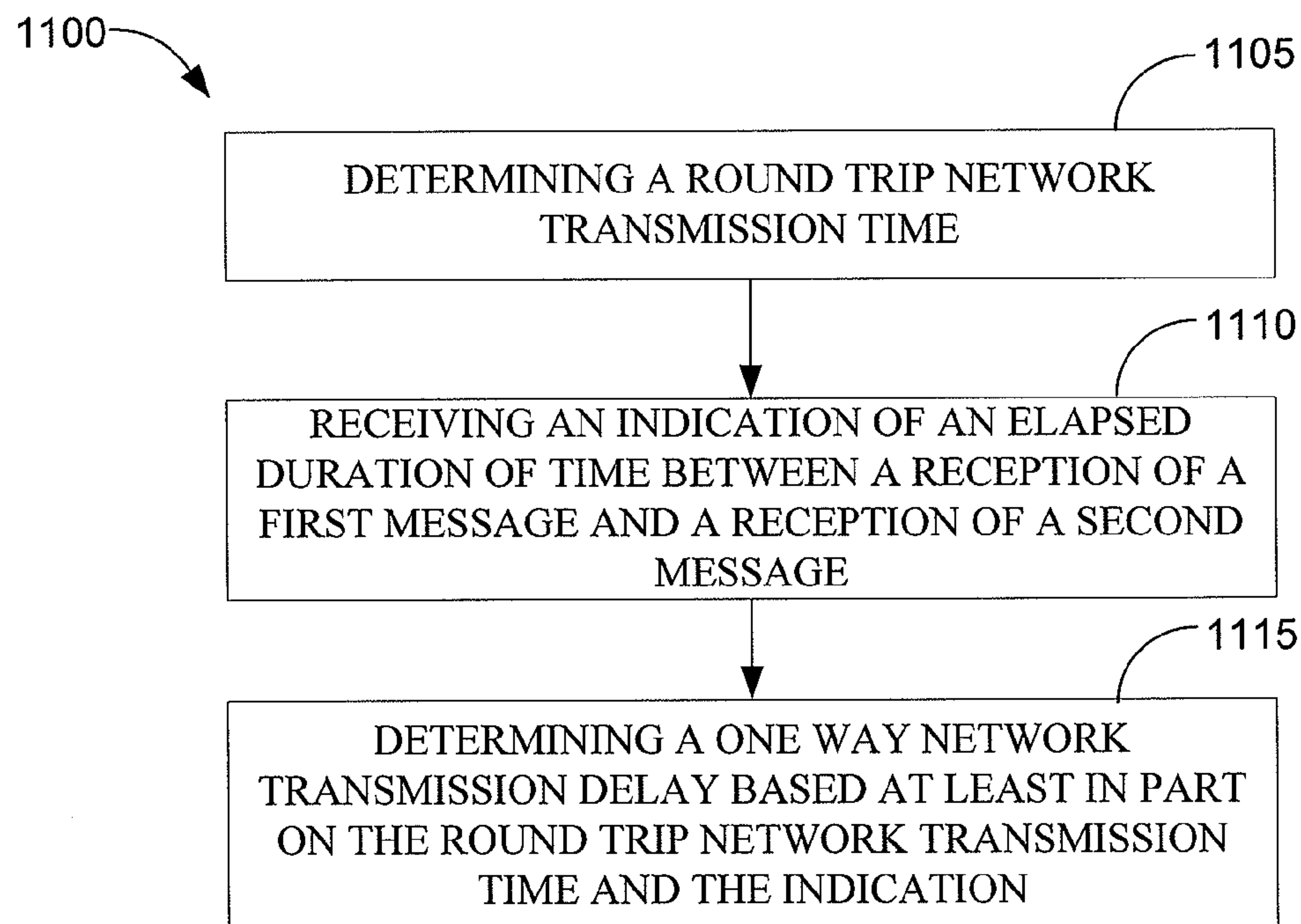
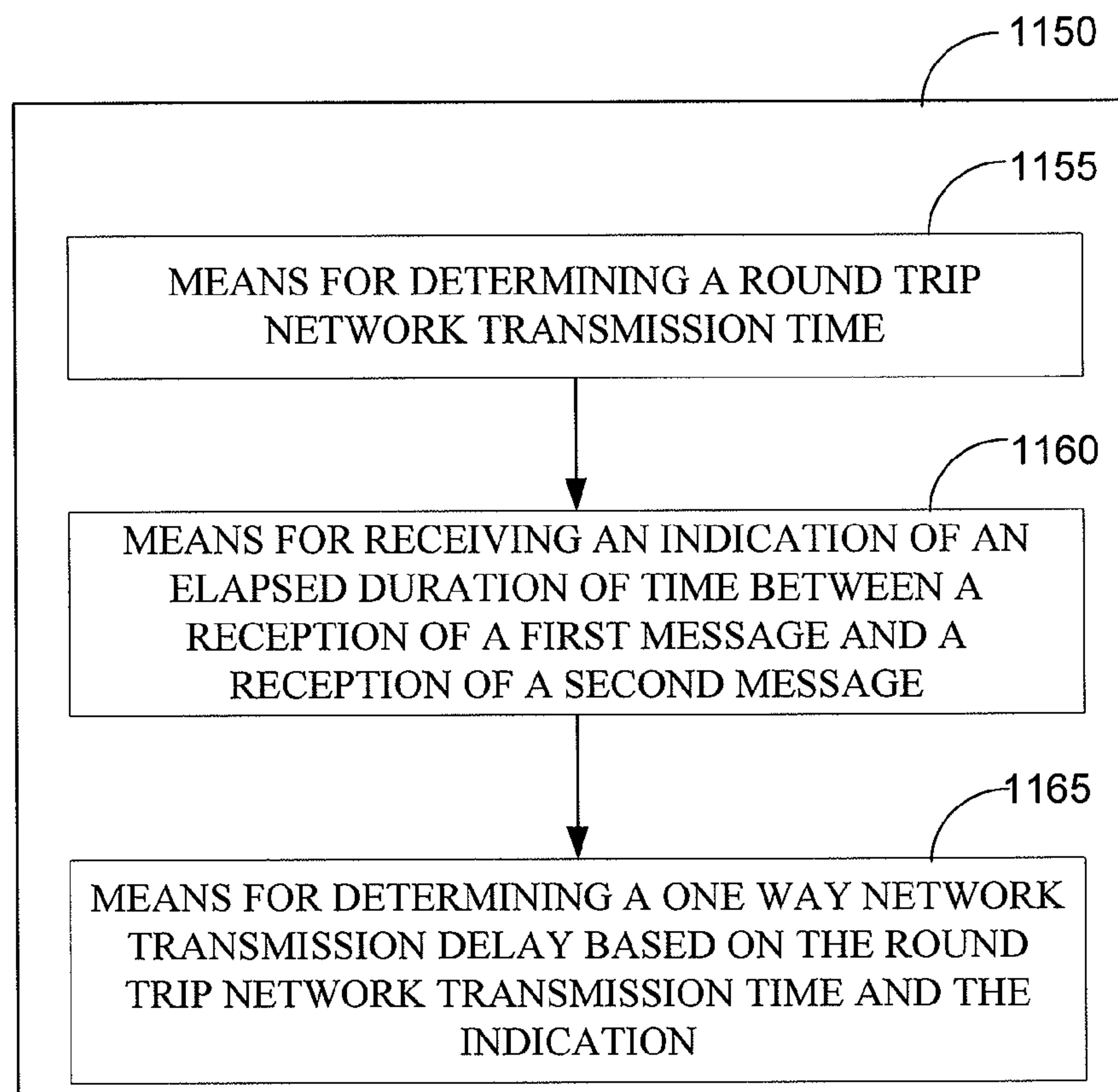


FIG. 10B

*FIG. 11A**FIG. 11B*

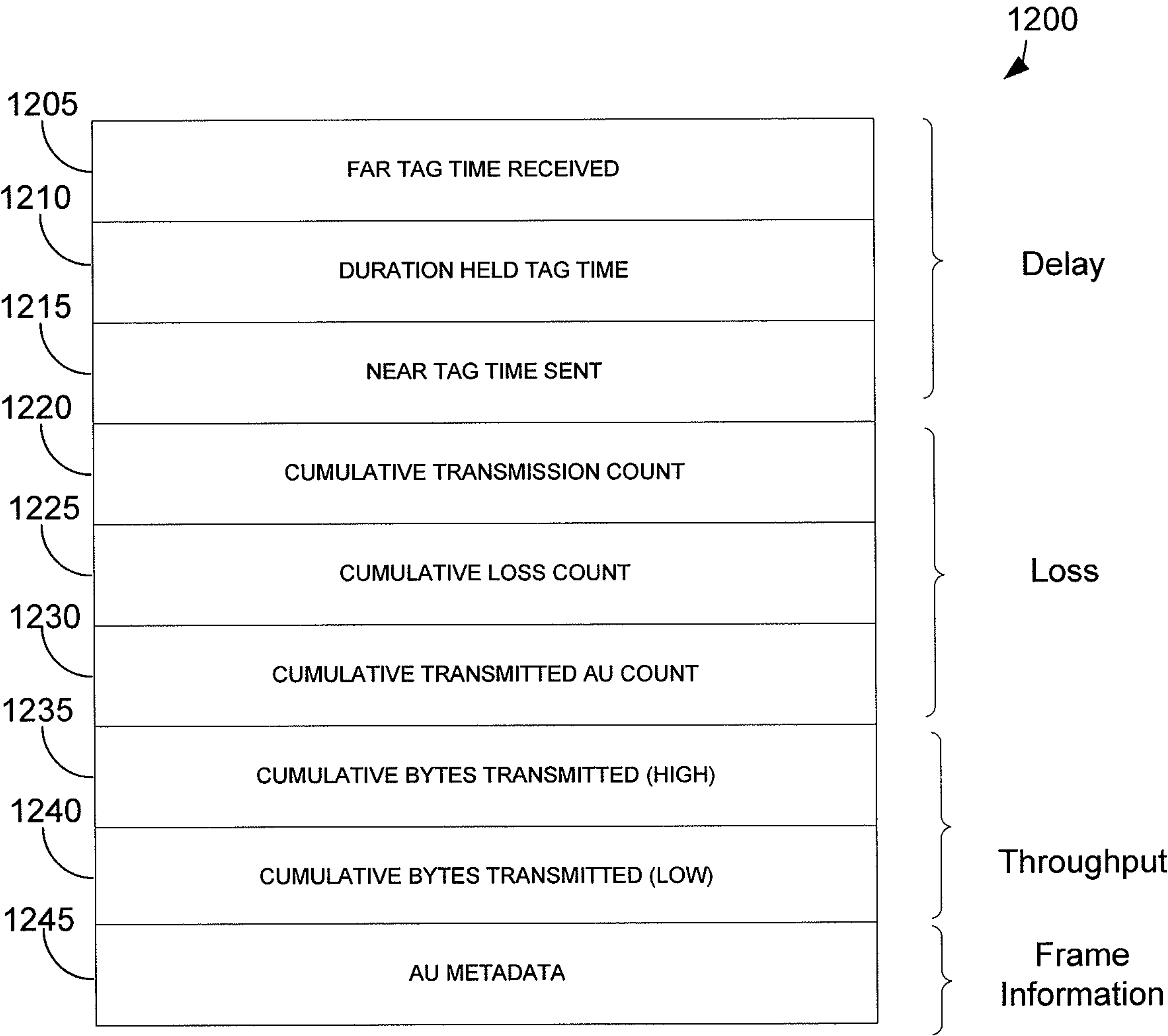
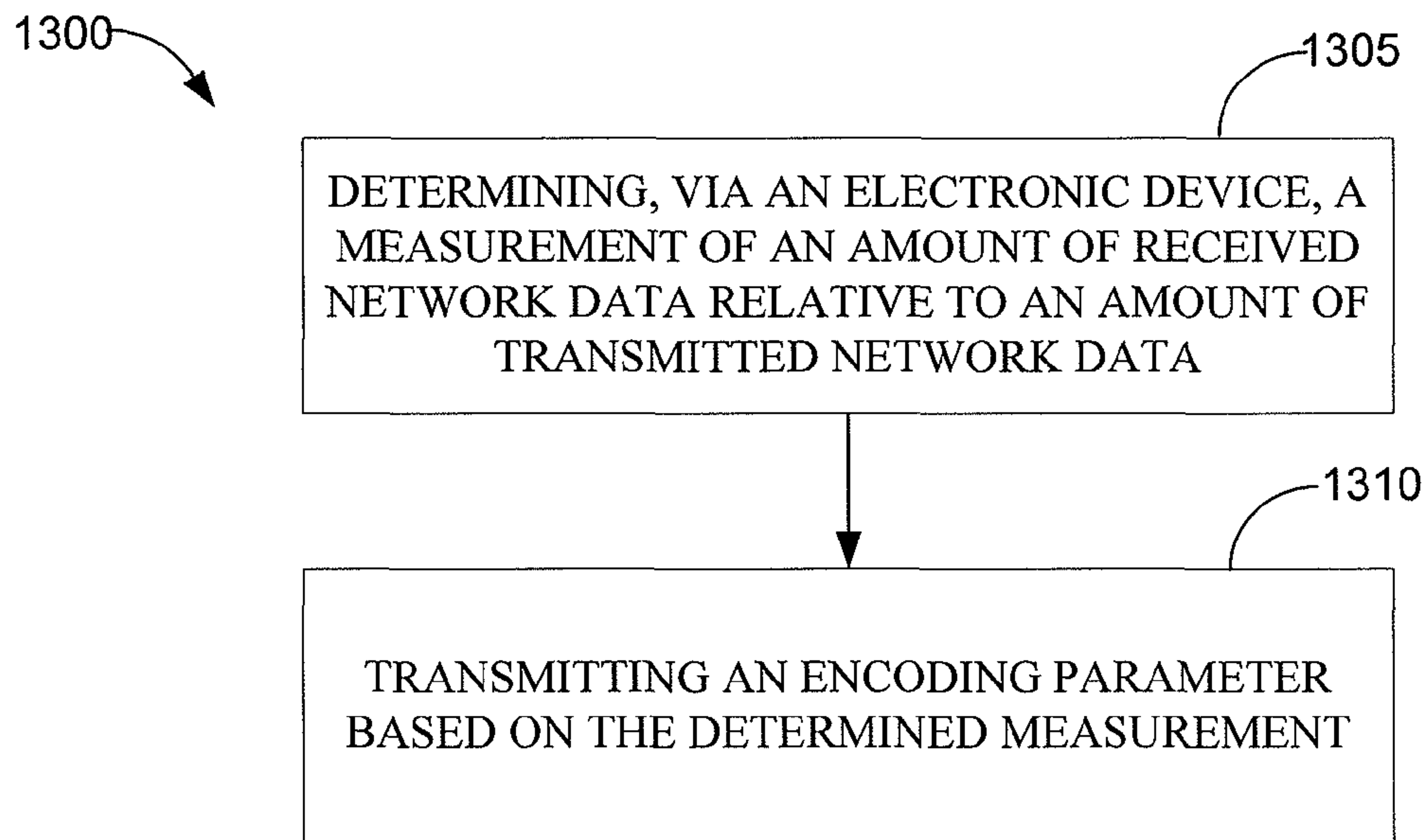
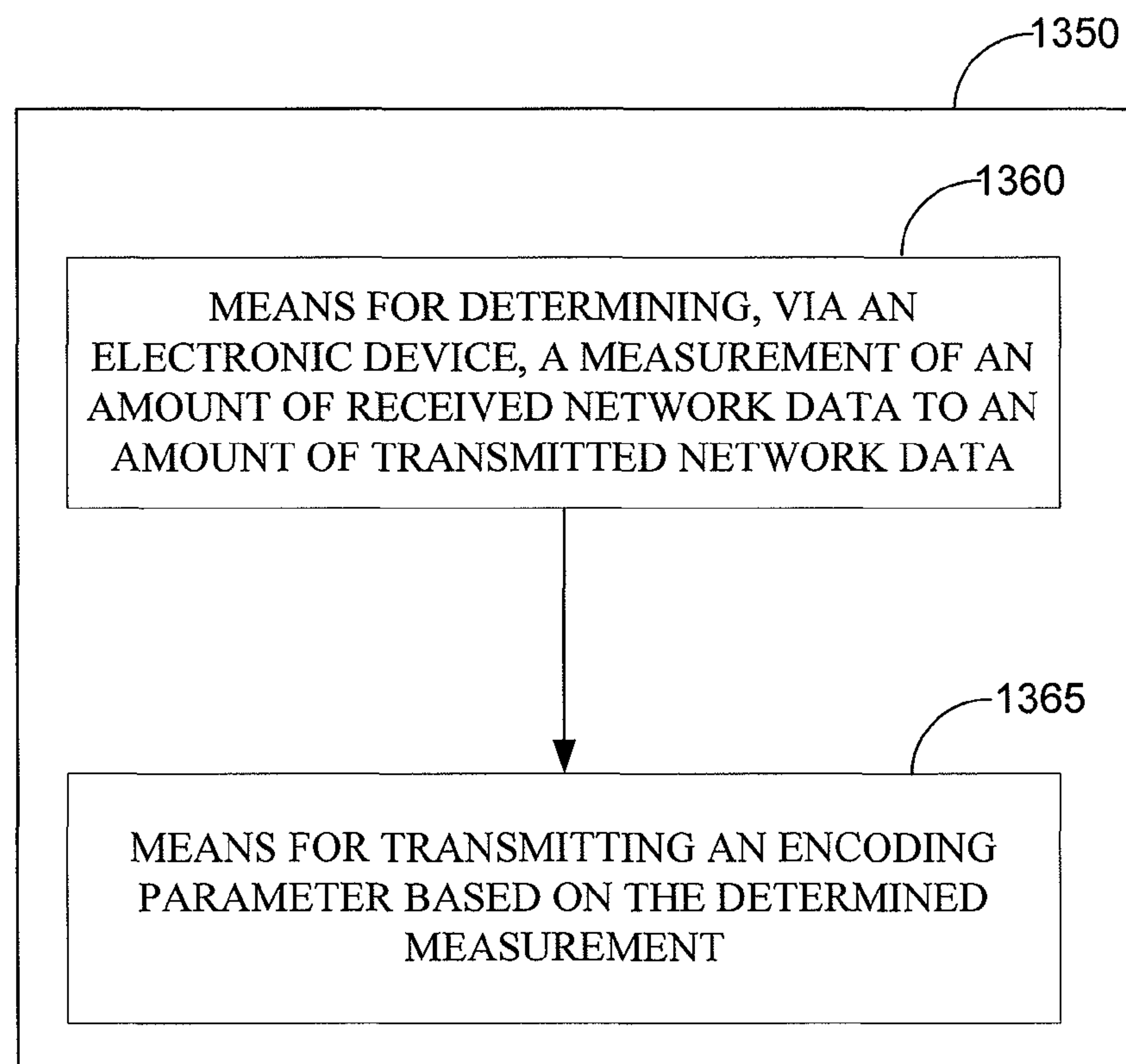


FIG. 12

*FIG. 13A**FIG. 13B*

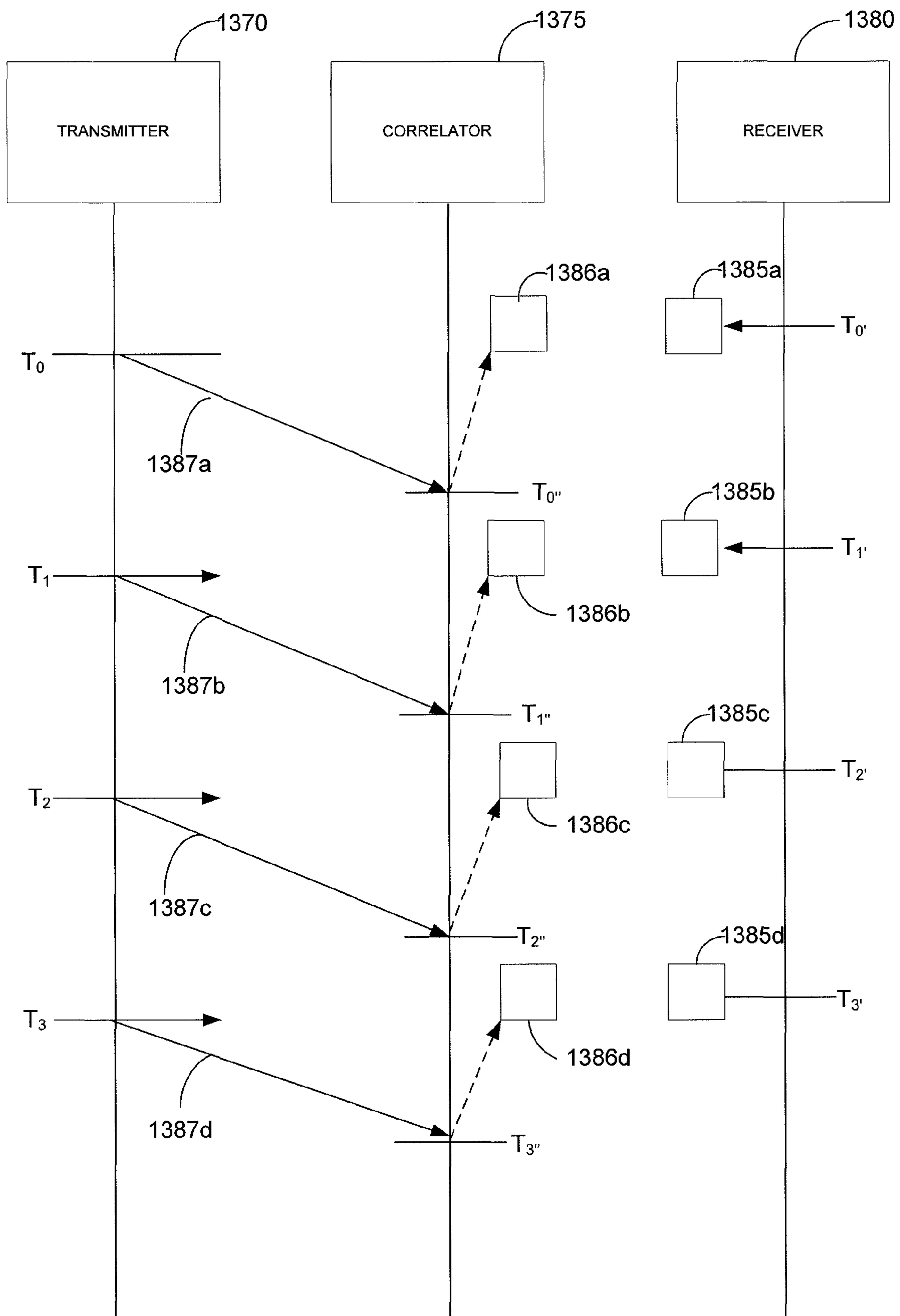
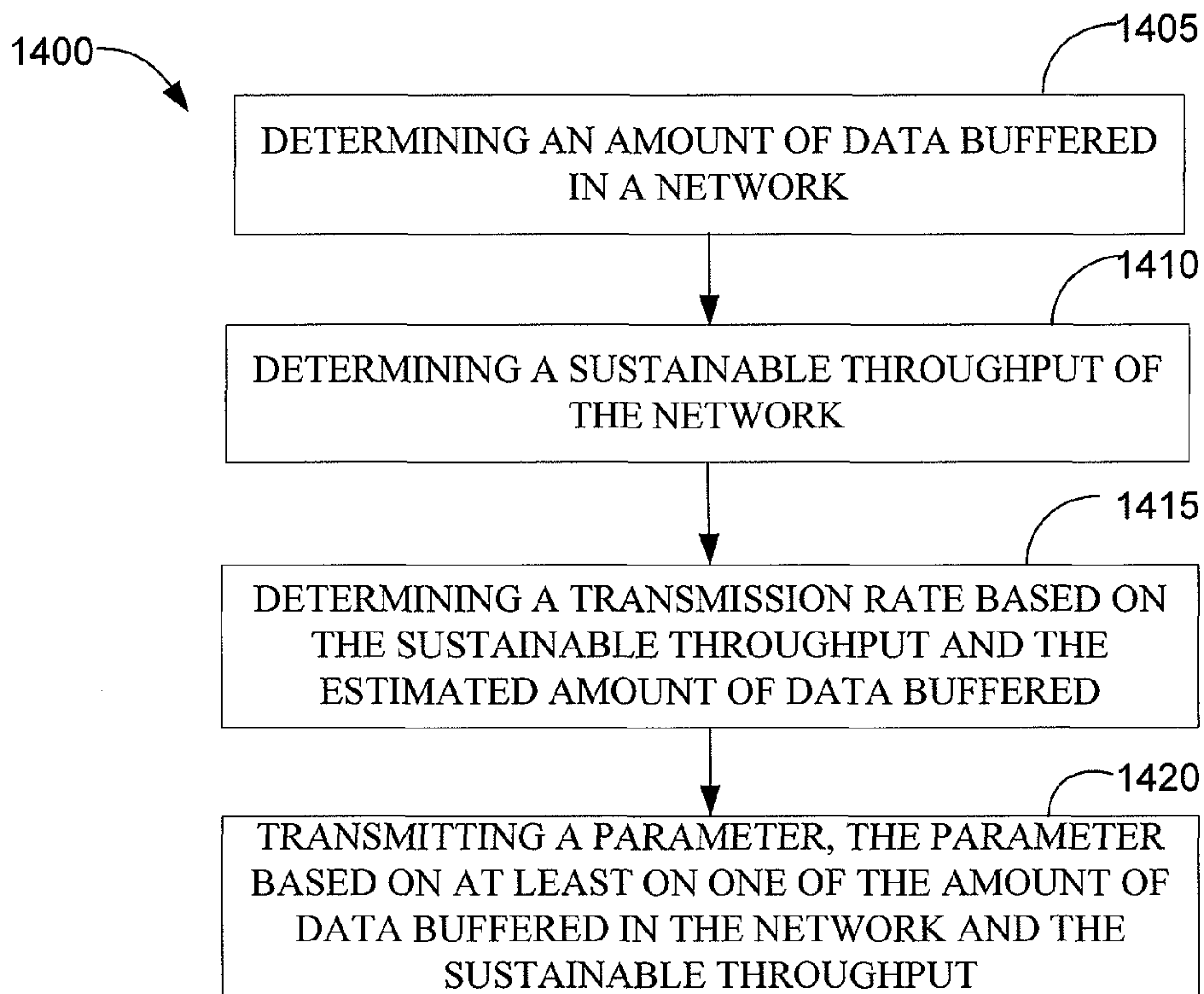
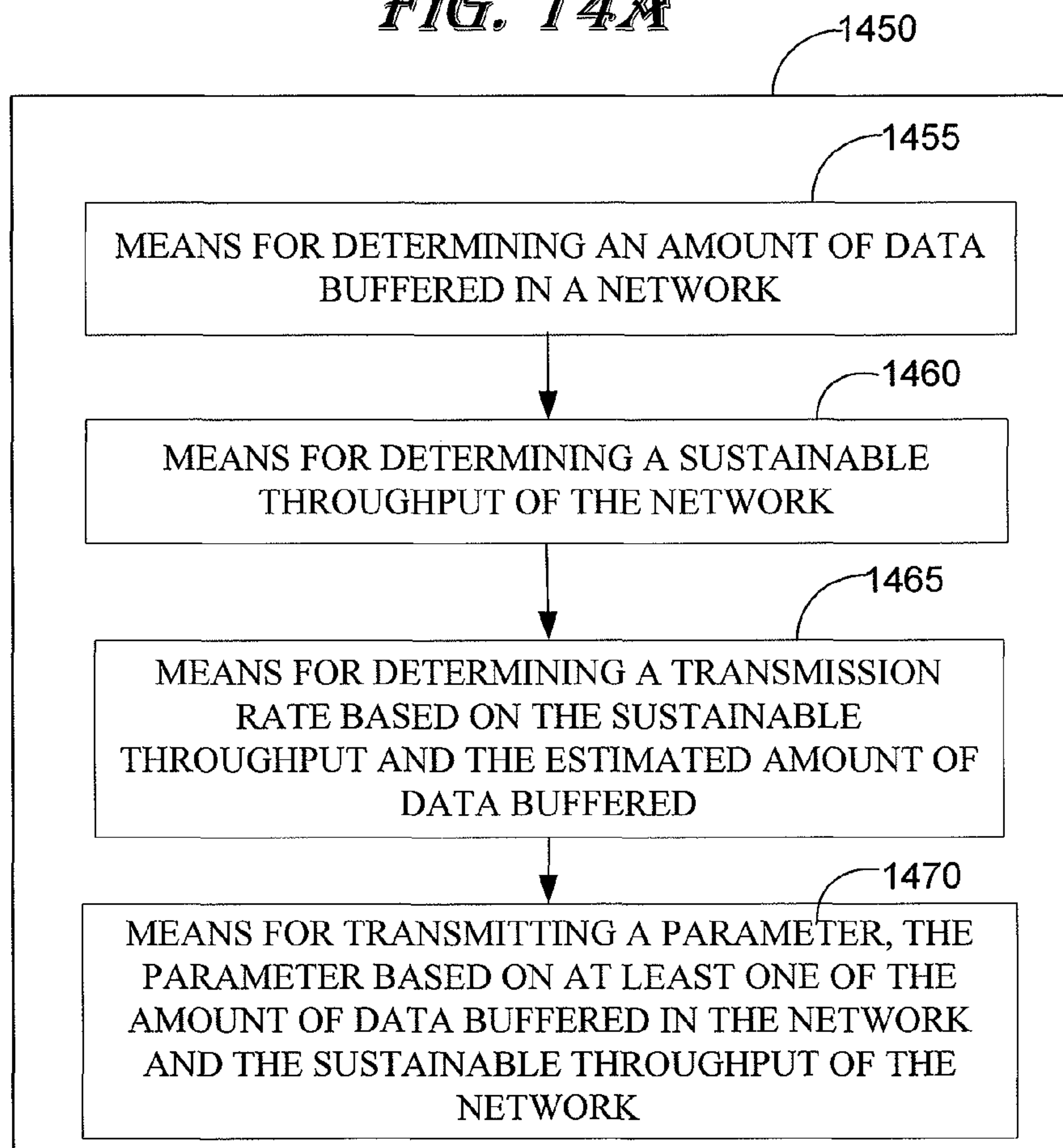
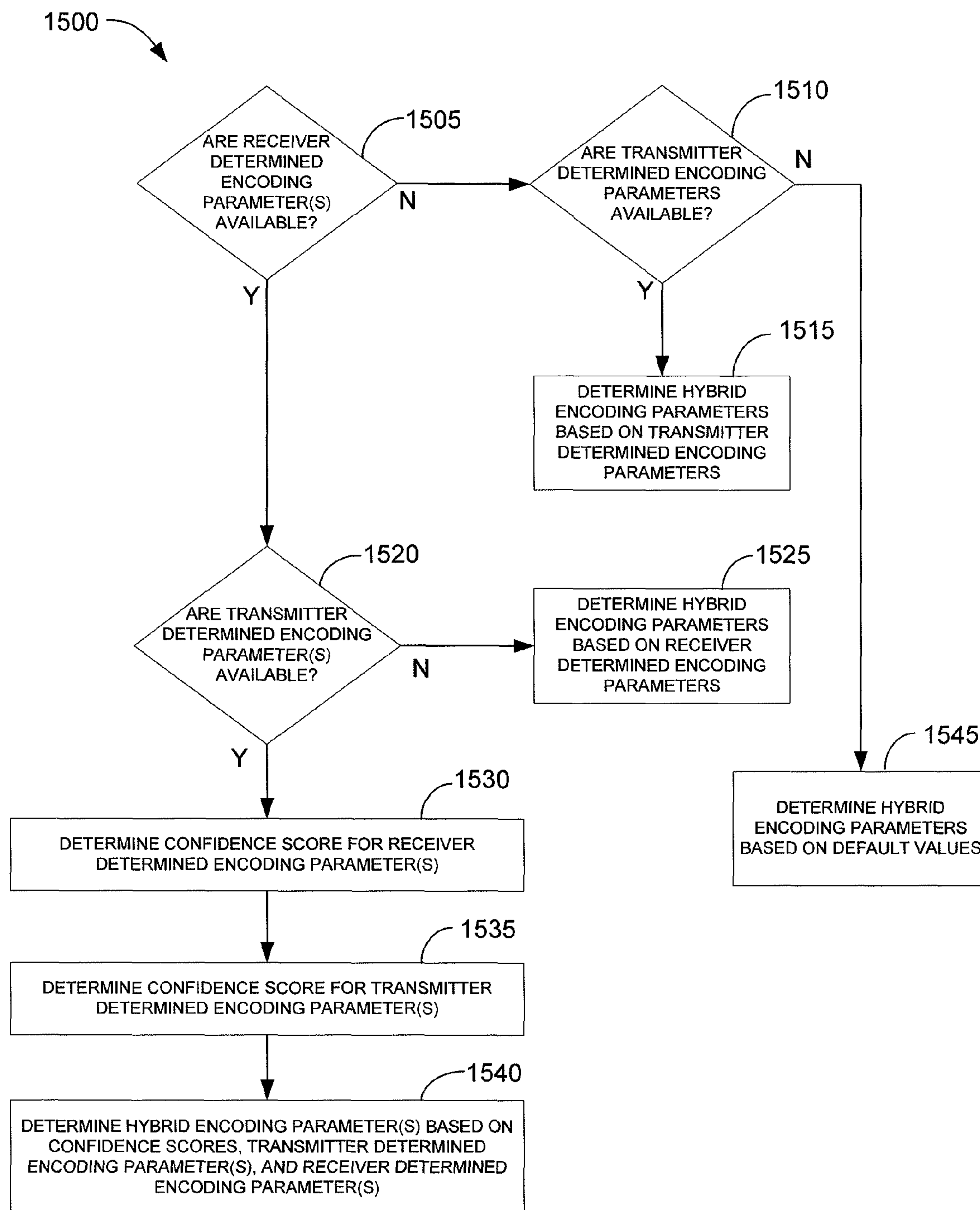
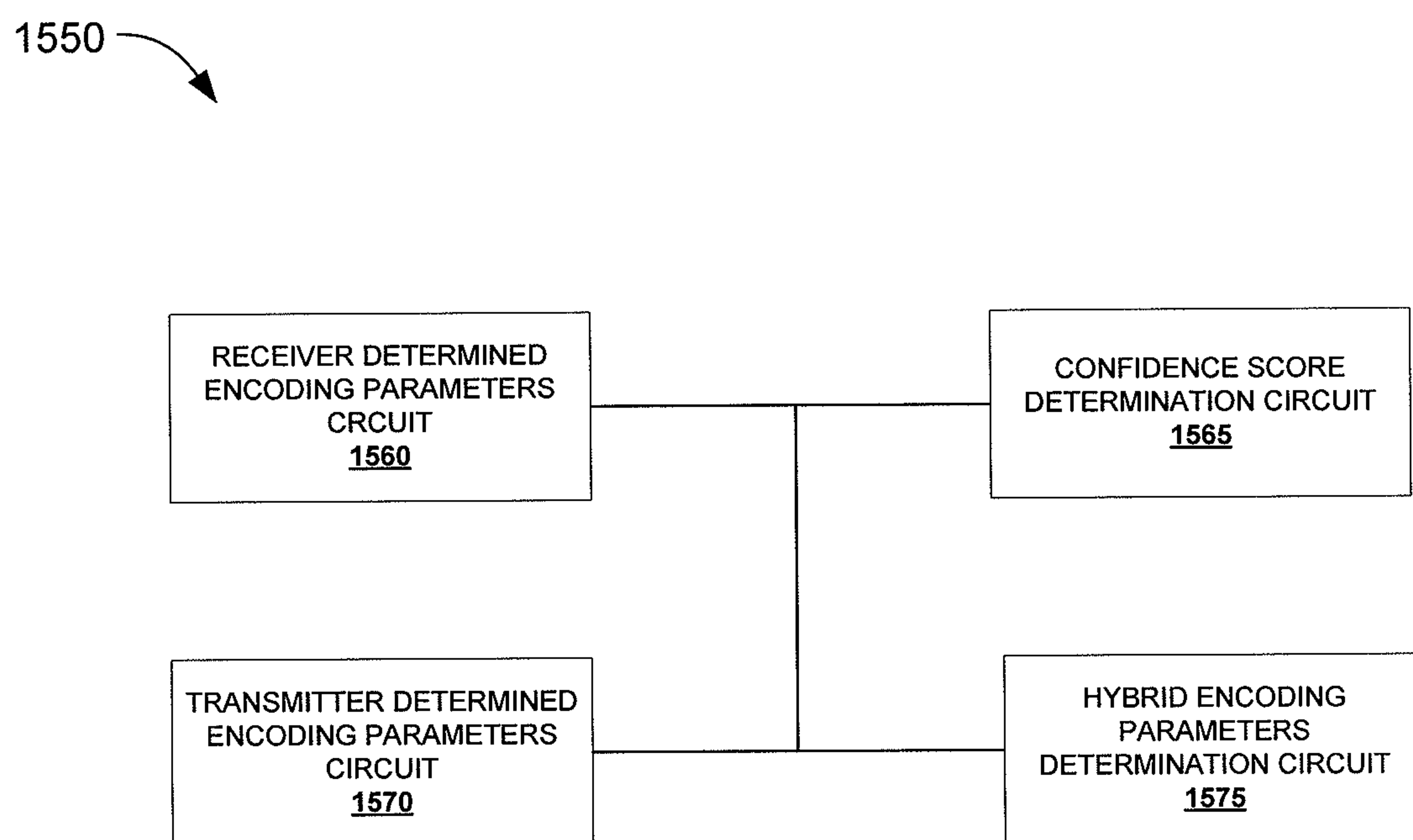
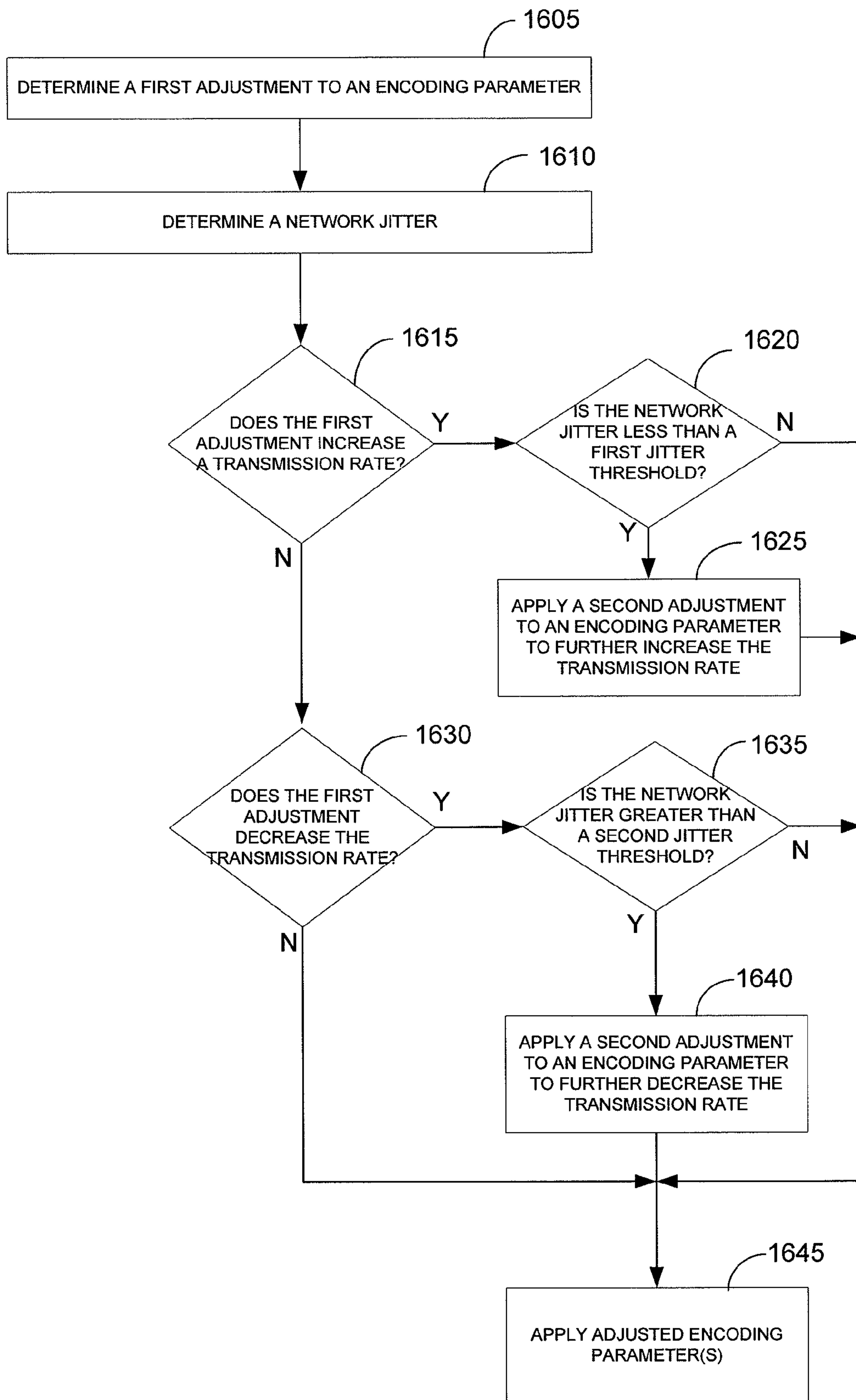


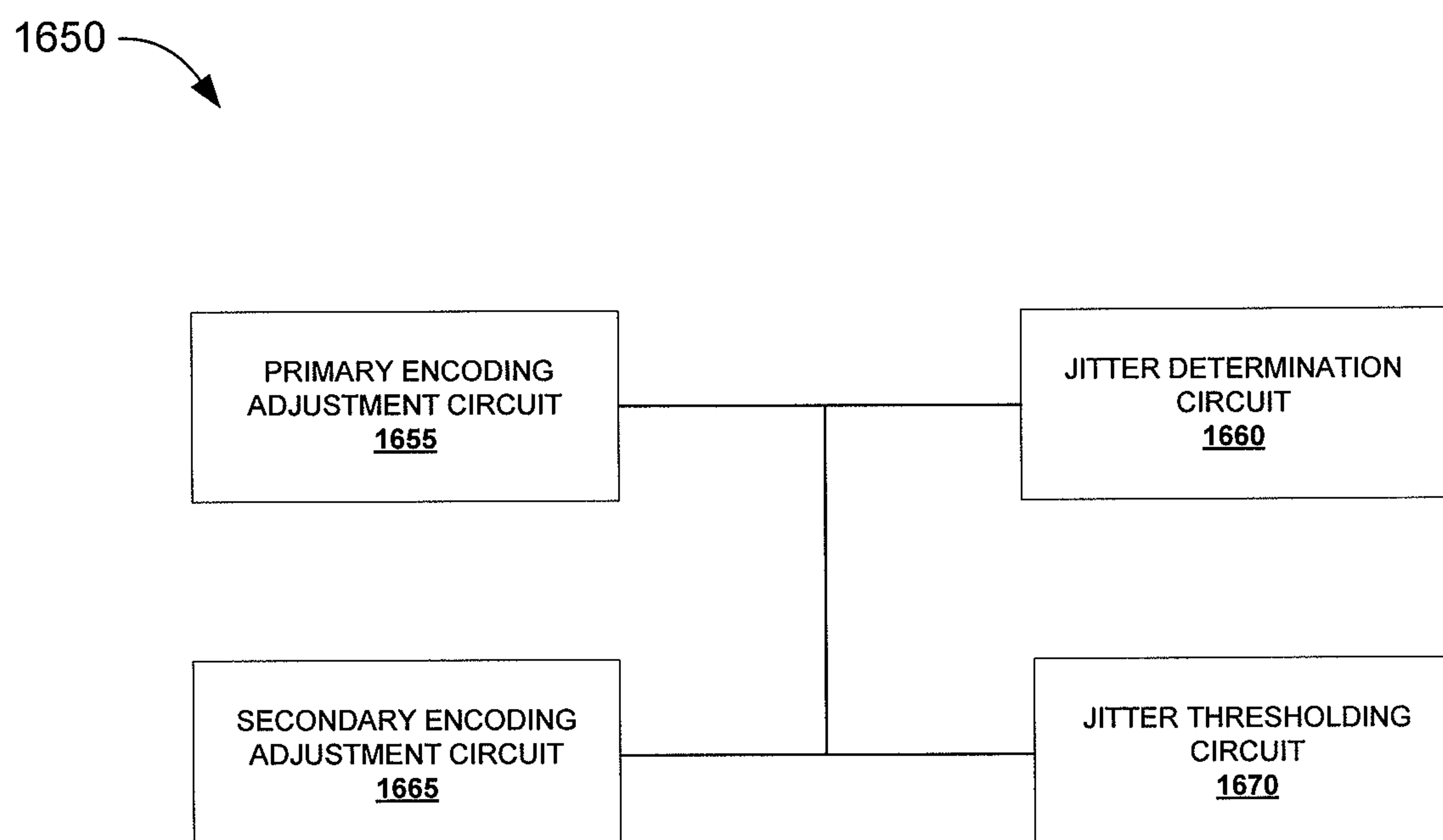
FIG. 13C

**FIG. 14A****FIG. 14B**

**FIG. 15A**

*FIG. 15B*

**FIG. 16A**

***FIG. 16B***

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DEVICE AND METHOD FOR ADAPTIVE RATE MULTIMEDIA COMMUNICATIONS ON A WIRELESS NETWORK

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Application 61/693,469, filed Aug. 27, 2012, and entitled “DEVICE AND METHOD FOR ADAPTIVE RATE MULTIMEDIA COMMUNICATIONS ON A WIRELESS NETWORK,” and assigned to the assignee hereof. This application also claims the benefit of U.S. Provisional Application 61/814,720, filed Apr. 22, 2013, and entitled “DEVICE AND METHOD FOR ADAPTIVE RATE MULTIMEDIA COMMUNICATIONS ON A WIRELESS NETWORK,” and assigned to the assignee hereof. The disclosures of these prior applications are considered part of this application, and are hereby incorporated by reference in their entirety. This application is related to U.S. application Ser. No. 13/975,030, entitled “DEVICE AND METHOD FOR ADAPTIVE RATE MULTIMEDIA COMMUNICATIONS ON A WIRELESS NETWORK,” filed on even date herewith, and is incorporated herein by reference, in its entirety.

BACKGROUND

1. Field

The present invention relates to encoding multimedia data on a wireless network, and more specifically to adapting one or more encoding parameters of the multimedia data based on a current capacity of the wireless network.

2. Background

Multimedia data may be encoded for transmission over a wireless network. When multimedia data is encoded, the methods and parameters of the encoding process may control the fidelity of the data provided to a receiver. When the receiver decodes the encoded data, for example, to play a video or audio file, the quality of the multimedia experience may at least in part relate to the fidelity of the encoded data.

The level of fidelity of the data provided may also affect the size of the encoded multimedia data. For example, high fidelity encoded data may be larger than encoded data providing a lower quality multimedia experience. Some networking environments, for example, some uncongested network environments, provide adequate capacity to transmit the high fidelity encoded data with a relatively low latency and packet loss rate. In these environments, the high fidelity data may provide a good user experience. Other network environments do not provide a capacity sufficient to transfer high fidelity data with an acceptable latency and loss rate. These networking environments may suffer from traffic congestion or service outages caused by equipment being offline or other reasons. A poor user experience may result in these environments.

The network capacity of a given network environment may itself vary between the uncongested and congested environments described above. For example, networks may experience peak usage periods that result in relatively high latencies and low bandwidth per user, with the further possibility of packet losses. Off-peak periods may provide improvements in latency and loss rates. In these networking environments, a transmission rate tailored to off-peak network capacities may result in a poor user experience during peak periods, as the high fidelity data transmitted during these periods may exceed the network’s capacity, resulting in dropped packets and high latencies. Similarly, transmission rates suitable for peak periods with acceptable latencies and loss rates may

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provide a lower fidelity user experience than is possible during off-peak periods. During off-peak periods when network capacity is relatively high, the lower transmission rates may underutilize network capacity.

SUMMARY

The systems, methods, and devices of the invention each have several aspects, no single one of which is solely responsible for its desirable attributes. Without limiting the scope of this invention as expressed by the claims which follow, some features will now be discussed briefly. After considering this discussion, and particularly after reading the section entitled “Detailed Description” one will understand how the features of this invention provide advantages that include identification and application of rotation amount and duration to pictures included in a multimedia presentation (e.g., video, sequence of pictures).

One aspect discloses is a method of encoding data. The method includes determining, via an electronic device, a measurement of an amount of received network data relative to an amount of transmitted network data; and adjusting an encoding parameter based at least in part on the measurement. In some aspects, the measurement is a ratio of the amount of received network data to the amount of transmitted network data. In other aspects, the measurement is a difference between the amount of received network data and the amount of transmitted network data. In some aspects, the method also includes receiving a quantity of data received by a receiver, and determining the received network data based at least in part on the quantity. In some aspects, the method includes receiving an encoding parameter value from a receiver, and adjusting the encoding parameter based at least on the received encoding parameter. In some aspects, the method also includes transmitting a quantity of data transmitted to the receiver. In some aspects, the method also includes determining a network jitter, wherein the encoding parameter is adjusted based at least on the network jitter. In some aspects, the method also includes determining if the adjustment of the encoding parameter will increase a transmission rate, and determining a second adjustment to a second encoding parameter that will further increase the transmission rate if the network jitter is below a first jitter threshold.

In some aspects, the encoding parameter and the second encoding parameter are different parameters. In some aspects, the method also includes determining if the adjustment of the encoding parameter will decrease a transmission rate; and determining a second adjustment to a second encoding parameter that will further decrease the transmission rate if the network jitter is above a second jitter threshold. In some aspects, the encoding parameter and the second encoding parameter are different parameters.

In some aspects, the method also includes determining a delay in receiving the quantity of data received by the receiver, and determining the transmitted network data based at least in part on the delay. In some aspects, the method also includes determining a transmission rate based on the determined measurement, wherein the encoding parameter is adjusted based at least in part on the transmission rate.

Another aspect, disclosed is a method of determining a transmission rate. The method includes determining an amount of data buffered in a network, determining a sustainable throughput of the network, and determining a transmission rate based at least in part on the sustainable throughput and the amount of data buffered. In some aspects, the method also includes adjusting an encoding parameter based at least in part on the transmission rate. In some aspects, the method

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also includes transmitting a parameter based one at least one of the amount of data buffered in the network and the sustainable throughput of the network. In some aspects, the method transmits the transmission rate.

In some aspects, the amount of data buffered in a network is determined based at least in part on a duration of time a transmission rate exceeded a network capacity. In some aspects, the amount of data buffered in a network is determined based at least in part on a difference between a transmission rate and a network capacity.

Another aspect disclosed is a method of determining a network round trip time. The method includes transmitting information identifying a time, receiving information identifying the transmitted time at a receive time, and determining the network round trip time based at least in part on the information and the receive time. In some aspects, the information identifying a time is a timestamp and the information identifying the transmitted time is the timestamp. In some aspects, the method also includes determining a delay between when the transmitted information is received and the received information is transmitted. In these aspects, the network round trip time is determined based on the delay. In some aspects, transmitting the information identifying a time and receiving information identifying the transmitted time are performed iteratively, wherein the time is different for each iteration, and the round trip time is determined based at least in part on each different time. In some aspects, the network round trip time is determined based on an average.

Another aspect disclosed is a method for determining a network queue drain duration. The method includes determining, via an electronic device, a measurement of an amount of transmitted network data relative to an amount of received network data, determining an amount of data buffered in a network, and determining the network queue drain duration based at least in part on the measurement and the amount of data buffered. In some aspects, the measurement is a ratio of the amount of received network data to the amount of transmitted network data. In other aspects, the measurement is a difference between the amount of received network data and the amount of transmitted network data.

In some aspects, the method also includes determining a duration of time when a transmission rate exceeds a sustainable network throughput, determining how much the transmission rate exceeded the sustainable network throughput, and determining the amount of data buffered in the network based at least in part on how much the transmission rate exceeded the sustainable network throughput and the duration.

In some aspects, the method also includes receiving a quantity of data received by a receiver, and determining the received network data based at least in part on the quantity. In some aspects, the method includes determining a delay in receiving the quantity of data received by the receiver, and determining the transmitted network data based at least in part on the delay. In some aspects, the method includes receiving a quantity of data transmitted by a transmitter, and determining the transmitted network data based at least in part on the quantity of data transmitted. In some aspects, the method also includes determining a delay in receiving the quantity of data transmitted by the transmitter, and determining the received network data based at least in part on the delay.

Another aspect disclosed is a method of determining a one way network transmission delay. The method includes determining a round trip network transmission time, receiving an indication of an elapsed time between a reception of a first message and a reception of a second message, and determin-

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ing the one way network transmission delay based at least in part on the round trip network transmission time and the indication.

In some aspects, the method includes transmitting the first message at a first time, transmitting the second message at a second time, and determining the one way network transmission delay based at least in part on the first time and the second time.

In some aspects, the one way network transmission time is determined based on an elapsed duration of time between the first time and the second time. In some aspects, the one way network transmission delay is determined based on a ratio of an elapsed duration of time between the first time and the second time, and an elapsed duration of time between the reception of the first message and the reception of the second message.

Another aspect discloses is an apparatus for encoding data. The apparatus includes a processor configured to: determine a measurement of an amount of transmitted network data relative to an amount of received network data, and adjust an encoding parameter based at least in part on the measurement. In some aspects, the processor is configured to determine a ratio of the amount of received network data to the amount of transmitted network data as the measurement. In other aspects, the processor is configured to determine the measurement as a difference between the amount of received network data and the amount of transmitted network data. In some aspects, the apparatus also includes a receiver configured to receive a quantity of data received by a receiver, wherein the processor is further configured to determine the received network data based at least in part on the quantity. In some aspects, the apparatus also includes a receiver configured to receive an encoding parameter value from a receiver, wherein the processor is configured to further adjust the encoding parameter based at least on the received encoding parameter. In some aspects, the apparatus also includes transmitting a quantity of data transmitted to the receiver. In some aspects, the apparatus also includes a processor configured to determine a network jitter, wherein the processor is configured to adjust the encoding parameter based at least on the network jitter. In some aspects, the processor is further configured to determine if the adjustment of the encoding parameter will increase a transmission rate, and determine a second adjustment to a second encoding parameter that will further increase the transmission rate if the network jitter is below a first jitter threshold. In some aspects, the encoding parameter and the second encoding parameter are different parameters. In some aspects, the processor is further configured to determine if the adjustment of the encoding parameter will decrease a transmission rate, and determine a second adjustment to a second encoding parameter that will further decrease the transmission rate if the network jitter is above a second jitter threshold. In some aspects, the encoding parameter and the second encoding parameter are different parameters. In some aspects, the processor is further configured to determine a delay in receiving the quantity of data received by the receiver, and determine the transmitted network data based at least in part on the delay. In some aspects, the processor is further configured to determine a transmission rate based on the determined measurement, wherein the encoding parameter is adjusted based at least in part on the transmission rate.

Another aspect disclosed is an apparatus for determining a transmission rate. The apparatus includes a processor configured to determine an amount of data buffered in a network, determine a sustainable throughput of the network, and determine a transmission rate based at least in part on the sustain-

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able throughput and the amount of data buffered. In some aspects, the processor is further configured to adjust an encoding parameter based at least in part on the transmission rate. In some aspects, the apparatus also includes a transmitter configured to transmit a parameter based on at least one of the amount of data buffered in a network and the sustainable throughput of the network. In some aspects, the processor is further configured to transmit the transmission rate. In some aspects, the processor is configured to determine the amount of data buffered in a network based at least in part on a duration of time a transmission rate exceeded a network capacity. In some aspects, the processor is configured to determine the amount of data buffered in a network based at least in part on a difference between a transmission rate and a network capacity.

Another aspect disclosed is an apparatus for determining a network round trip time. The apparatus includes a transmitter configured to transmit information identifying a time, a receiver information identifying the transmitted time at a receive time, and a processor configured to determine the network round trip time based at least in part on the information and the receive time. In some aspects, the information identifying a time is a timestamp and the information identifying the transmitted time is the timestamp. In some aspects, the apparatus also includes a processor configured to determine a delay between when the transmitted information is received and the received information is transmitted, wherein the network round trip time is determined based on the delay.

In some aspects, the transmitter is further configured to transmit the information identifying a time iteratively and the receiver is further configured to receive information identifying the transmitted time iteratively, wherein the time is different for each iteration, and the round trip time is determined based at least in part on each different time. In some aspects, the processor is configured to determine the network round trip time based on an average.

Another aspect disclosed is an apparatus for determining a network queue drain duration. The apparatus includes a processor configured to determine, a measurement of an amount of transmitted network data relative to an amount of received network data, determine an amount of data buffered in a network, and determine the network queue drain duration based at least in part on the measurement and the amount of data buffered. In some aspects, the processor is configured to determine the measurement as a ratio of the amount of received network data to the amount of transmitted network data. In other aspects, the processor is configured to determine the measurement as a difference between the amount of received network data and the amount of transmitted network data.

In some aspects, the processor is further configured to determine a duration of time when a transmission rate exceeds a sustainable network throughput, determine how much the transmission rate exceeded the sustainable network throughput, and determine the amount of data buffered in the network based at least in part on how much the transmission rate exceeded the sustainable network throughput and the duration. In some aspects, the apparatus also includes a receiver configured to receive a quantity of data received by a receiver, wherein the processor is further configured to determine the received network data based at least in part on the quantity. In some aspects, the processor is further configured to determine a delay in receiving the quantity of data received by the receiver, and determine the transmitted network data based at least in part on the delay.

In some aspects, the apparatus also includes a receiver configured to receive a quantity of data transmitted by a

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transmitter, wherein the processor is further configured to determine the transmitted network data based at least in part on the quantity. In some aspects, the processor is further configured to determine a delay in receiving the quantity of data transmitted by the transmitter, and determine the received network data based at least in part on the delay.

Another aspect disclosed is an apparatus for determining a one way network transmission delay. The apparatus includes a processor configured to determining a round trip network transmission time, and a receiver configured to receive an indication of an elapsed duration of time between a reception of a first message and a reception of a second message, wherein the processor is further configured to determine the one way network transmission delay based at least in part on the round trip network transmission time and the indication. In some aspects, the apparatus includes a transmitter configured to transmit the first message at a first time, and configured to transmit the second message at a second time, wherein the processor is further configured to determine the one way network transmission delay based at least in part on the first time and the second time. In some aspects, the one way network transmission delay is determined based on an elapsed duration of time between the first time and the second time. In some aspects, the processor is configured to determine the one way network transmission delay based on a ratio of the elapsed duration of time between the first time and the second time, and the elapsed duration of time between the reception of the first message and the reception of the second message.

Another aspect disclosed is an apparatus for encoding data. The apparatus includes means for determining, a measurement of an amount of transmitted network data relative to an amount of received network data, and means for adjusting an encoding parameter based at least in part on the determined measurement. In some aspects, the means for determining a measurement is configured to determine a ratio of the amount of received network data to the amount of transmitted network data. In other aspects, the means for determining a measurement is configured to determine a difference between the amount of received network data and the amount of transmitted network data.

In some aspects, the apparatus also includes means for receiving a quantity of data received by a receiver, and means for determining the received network data based at least in part on the quantity. In some aspects, the apparatus also includes means for determining a delay in receiving the quantity of data received by the receiver, and means for determining the transmitted network data based at least in part on the delay. In some aspects, the apparatus also includes means for determining a transmission rate based on the determined measurement, wherein the encoding parameter is adjusted based at least in part on the transmission rate. In some aspects, the apparatus also includes means for receiving an encoding parameter value from a receiver, wherein the means for adjusting the encoding parameter is configured to adjust the encoding parameter based at least on the received encoding parameter. In some aspects, the apparatus also includes means for transmitting a quantity of data transmitted to the receiver. In some aspects, the apparatus includes means for determining a network jitter, wherein the means for adjust the encoding parameter is configured to adjust the encoding parameter based at least on the network jitter. In some aspects, the apparatus includes means for determining if the adjustment of the encoding parameter will increase a transmission rate, means for determining a second adjustment to a second encoding parameter that will further increase the transmission rate if the network jitter is below a first jitter threshold. In

some aspects, the encoding parameter and the second encoding parameter are different parameters.

In some aspects, the apparatus also includes means for determining if the adjustment of the encoding parameter will decrease a transmission rate, and means for determining a second adjustment to a second encoding parameter that will further decrease the transmission rate if the network jitter is above a second jitter threshold. In some aspects, the encoding parameter and the second encoding parameter are different parameters.

Another aspect disclosed is an apparatus for determining a transmission rate. The apparatus includes means for determining an amount of data buffered in a network, means for determining a sustainable throughput of the network, and means for determining a transmission rate based at least in part on the sustainable throughput and the amount of data buffered. In some aspects, the apparatus includes means for adjusting an encoding parameter based at least in part on the transmission rate. In some aspects, the apparatus also includes means for transmitting a parameter based on at least one of the amount of data buffered in the network and the sustainable throughput of the network. In some aspects, the apparatus also includes means for transmitting the transmission rate to a transmitting node. In some aspects, the amount of data buffered in a network is determined based at least in part on a duration of time a transmission rate exceeded a network capacity. In some aspects, the amount of data buffered in a network is determined based at least in part on a difference between a transmission rate and a network capacity.

Another aspect disclosed is an apparatus for determining a network round trip time. The apparatus includes means for transmitting information identifying a time, means for receiving information identifying the transmitted time at a receive time; and means for determining the network round trip time based at least in part on the information and the receive time. In some aspects, the information identifying a time is a timestamp and the information identifying the transmitted time is the timestamp. In some aspects, the apparatus also includes means for determining a delay between when the transmitted information is received and the received information is transmitted, wherein the network round trip time is determined based on the delay. In some aspects, the means for transmitting the information identifying a time and the means for receiving information identifying the transmitted time perform the transmitting and receiving iteratively, wherein the time is different for each iteration, and the round trip time is determined based at least in part on each different time. In some aspects, the network round trip time is determined based on an average.

Another aspect disclosed is an apparatus for determining a network queue drain duration. The apparatus includes means for determining a measurement of an amount of transmitted network data relative to an amount of received network data, means for determining an amount of data buffered in a network, and means for determining the network queue drain duration based at least in part on the measurement and the amount of data buffered. In some aspects, the means for determining a measurement is configured to determine a ratio of the amount of received network data to the amount of transmitted network data. In other aspects, the means for determining a measurement is configured to determine a difference between the amount of received network data and the amount of transmitted network data.

In some aspects, the apparatus also includes means for determining a duration of time when a transmission rate exceeds a sustainable network throughput, means for deter-

mining how much the transmission rate exceeded the sustainable network throughput, and means for determining the amount of data buffered in the network based at least in part on how much the transmission rate exceeded the sustainable network throughput and the duration.

In some aspects, the apparatus also includes means for receiving a quantity of data transmitted by a transmitter, and means for determining the transmitted network data based at least in part on the quantity. In some aspects, the apparatus also includes means for determining a delay in receiving the quantity of data transmitted by the transmitter, and means for determining the received network data based at least in part on the delay. In some aspects, the apparatus includes means for receiving a quantity of data received by a receiver, and means for determining the received network data based at least in part on the quantity. In some aspects, the apparatus also includes means for determining a delay in receiving the quantity of data received by the receiver, and means for determining the transmitted network data based at least in part on the delay.

Another aspect disclosed is an apparatus for determining a one way network transmission delay. The apparatus includes means for determining a round trip network transmission time, means for receiving an indication of an elapsed duration of time between a reception of a first message and a reception of a second message, and means for determining the one way network transmission delay based at least in part on the round trip network transmission time and the indication. In some aspects, the apparatus also includes means for transmitting the first message at a first time, means for transmitting the second message at a second time, and means for determining the one way network transmission delay based at least in part on the first time and the second time. In some aspects, the means for determining the one way network transmission delay is configured to determine the one way network transmission delay based on an elapsed duration of time between the first time and the second time. In some aspects, the one way network transmission time is determined based on a ratio of the elapsed duration of time between the first time and the second time, and elapsed duration of time between the reception of the first message and the reception of the second message.

Another aspect disclosed is a non-transitory, computer readable media storing instructions that when executed, cause a processor to perform a method of determining a measurement of an amount of transmitted network data relative to an amount of received network data; and adjusting an encoding parameter based at least in part on the determined measurement. In some aspects, the measurement is a ratio of the amount of received network data to the amount of transmitted network data. In other aspects, the measurement is a difference between the amount of received network data and the amount of transmitted network data.

In some aspects, the method also includes receiving a quantity of data received by a receiver, and determining the received network data based at least in part on the quantity.

In some aspects, the method also includes receiving an encoding parameter value from a receiver, and adjusting the encoding parameter based at least on the received encoding parameter. In some aspects, the method also includes transmitting a quantity of data transmitted to the receiver. In some aspects, the method also includes determining a network jitter, wherein the encoding parameter is further adjusted based at least on the network jitter. In some aspects, the method also includes determining if the adjustment of the encoding parameter will increase a transmission rate; and determining a second adjustment to a second encoding parameter that will

further increase the transmission rate if the network jitter is below a first jitter threshold. In some aspects, the encoding parameter and the second encoding parameter are different parameters. In some aspects, the method also includes determining if the adjustment of the encoding parameter will decrease a transmission rate, and determining a second adjustment to a second encoding parameter that will further decrease the transmission rate if the network jitter is above a second jitter threshold. In some aspects, the encoding parameter and the second encoding parameter are different parameters. In some aspects, the method also includes determining a delay in receiving the quantity of data received by the receiver, and determining the transmitted network data based at least in part on the delay. In some aspects, the method also includes determining a transmission rate based on the determined measurement, wherein the encoding parameter is adjusted based at least in part on the transmission rate.

Another aspect disclosed is a non-transitory, computer readable media storing instructions that when executed, cause a processor to perform a method. The method includes determining an amount of data buffered in a network, determining a sustainable throughput of the network, and determining a transmission rate based at least in part on the sustainable throughput and the amount of data buffered. In some aspects, the method includes adjusting an encoding parameter based at least in part on the transmission rate. In some aspects, the method also includes transmitting a parameter based on at least one of the amount of data buffered in the network and the sustainable throughput of the network. In some aspects, the method also includes transmitting the transmission rate. In some aspects, the amount of data buffered in a network is determined based at least in part on a duration of time a transmission rate exceeded a network capacity. In some aspects, the method determines the amount of data buffered in a network based at least in part on a difference between a transmission rate and a network capacity.

Another aspect disclosed is a non-transitory, computer readable media storing instructions that when executed, cause a processor to perform a method of determining a round trip time. The method includes transmitting information identifying a time, receiving information identifying the transmitted time at a receive time, and determining the network round trip time based at least in part on the information and the receive time. In some aspects, the information identifying a time is a timestamp and the information identifying the transmitted time is the timestamp. In some aspects, the method also includes determining a delay between when the transmitted information is received and the received information is transmitted, wherein the network round trip time is determined based on the delay. In some aspects, transmitting the information identifying a time and receiving information identifying the transmitted time are performed iteratively, and the time is different for each iteration, and the round trip time is determined based at least in part on each different time. In some aspects, the network round trip time is determined based on an average.

Another aspect disclosed is a non-transitory, computer readable media storing instructions that when executed, cause a processor to perform a method of determining a network queue drain duration. The method includes determining a measurement of an amount of transmitted network data relative to an amount of received network data, determining an amount of data buffered in a network, and determining the network queue drain duration based at least in part on the measurement and the amount of data buffered. In some aspects, the measurement is a ratio of the amount of received network data to the amount of transmitted network data. In

other aspects, the measurement is a difference between the amount of received network data and the amount of transmitted network data.

In some aspects, the method also includes determining a duration of time when a transmission rate exceeds a sustainable network throughput, determining how much the transmission rate exceeded the sustainable network throughput, and determining the amount of data buffered in the network based at least in part on how much the transmission rate exceeded the sustainable network throughput and the magnitude. In some aspects, the method also includes receiving a quantity of data received by a receiver, and determining the received network data based at least in part on the quantity. In some aspects, the method also includes determining a delay in receiving the quantity of data received by the receiver, and determining the transmitted network data based at least in part on the delay.

In some aspects, the method includes receiving a quantity of data transmitted by a transmitter, and determining the transmitted network data based at least in part on the quantity. In some aspects, the method also includes determining a delay in receiving the quantity of data transmitted by the transmitter, and determining the received network data based at least in part on the delay.

In some aspects, the method also includes determining a round trip network transmission time; receiving an indication of an elapsed duration of time between a reception of a first message and a reception of a second message, and determining the one way network transmission delay based at least in part on the round trip network transmission time and the indication. In some aspects, the method also includes transmitting the first message at a first time, transmitting the second message at a second time, and determining the one way network transmission delay based at least in part on the first time and the second time. In some aspects, the one way network transmission delay is determined based on an elapsed duration of time between the first time and the second time. In some aspects, the one way network transmission delay is determined based on a ratio of the elapsed duration of time between the first time and the second time, and elapsed duration of time between the reception of the first message and the reception of the second message.

Another aspect disclosed is a method of transmitting an encoding parameter. The method includes determining, via an electronic device, a measurement of an amount of received network data relative to an amount of transmitted network data, and transmitting an encoding parameter, the encoding parameter based at least in part on the determined measurement. In some aspects, the measurement is a ratio of the amount of received network data to the amount of transmitted network data. In other aspects, the measurement is a difference between the amount of received network data and the amount of transmitted network data.

In some aspects, the method also includes receiving a quantity of data transmitted by a transmitter, and determining the transmitted network data based at least in part on the quantity. In some aspects, the method also includes transmitting the encoding parameter value to a transmitter. In some aspects, the method also includes transmitting a quantity of data received to the transmitter. In some aspects, the method also includes determining a network jitter, wherein the transmitted parameter is based at least on the network jitter. In some aspects, the method also includes determining if the adjustment of the encoding parameter will increase a transmission rate, and determining a second adjustment to a second encoding parameter that will further increase the transmission rate if the network jitter is below a first jitter

threshold. In some aspects, the encoding parameter and the second encoding parameter are different parameters. In some aspects, the method also includes determining if the adjustment of the encoding parameter will decrease a transmission rate, and determining a second adjustment to a second encoding parameter that will further decrease the transmission rate if the network jitter is above a second jitter threshold. In some aspects, the encoding parameter and the second encoding parameter are different parameters. In some aspects, the method also includes determining a delay in receiving the quantity of data transmitted by the transmitter; and determining the received network data based at least in part on the delay. In some aspects, the method also includes determining a transmission rate based on the determined measurement, wherein the transmitted parameter is based at least in part on the transmission rate.

Another aspect disclosed is an apparatus for transmitting an encoding parameter. The apparatus includes a processor configured to determine a measurement of an amount of received network data relative to an amount of transmitted network data, and a transmitter configured to transmit an encoding parameter, the encoding parameter based at least in part on the determined measurement. In some aspects, the processor is configured to determine the measurement as a ratio of the amount of received network data to the amount of transmitted network data. In other aspects, the processor is configured to determine the measurement as a difference between the amount of received network data and the amount of transmitted network data.

In some aspects, the apparatus also includes a receiver configured to receive a quantity of data transmitted by a transmitter, and a processor configured to determine the transmitted network data based at least in part on the quantity. In some aspects, the apparatus includes a transmitter configured to transmit the encoding parameter value to a transmitter. In some aspects, the apparatus also includes a transmitter configured to transmit a quantity of data received to the transmitter. In some aspects, the apparatus also includes a processor configured to determine a network jitter, wherein the transmitted parameter is based at least on the network jitter. In some aspects, the apparatus also includes a processor configured to determine if the adjustment of the encoding parameter will increase a transmission rate, and determine a second adjustment to a second encoding parameter that will further increase the transmission rate if the network jitter is below a first jitter threshold. In some aspects, the encoding parameter and the second encoding parameter are different parameters. In some aspects, the apparatus also includes a processor configured to determine if the adjustment of the encoding parameter will decrease a transmission rate, and determine a second adjustment to a second encoding parameter that will further decrease the transmission rate if the network jitter is above a second jitter threshold. In some aspects, the encoding parameter and the second encoding parameter are different parameters.

In some aspects, the apparatus also includes a processor configured to determine a delay in receiving the quantity of data transmitted by the transmitter, and determine the received network data based at least in part on the delay. In some aspects, the apparatus also includes a processor configured to determine a transmission rate based on the determined measurement, wherein the transmitted parameter is based at least in part on the transmission rate.

Another aspect disclosed is an apparatus for transmitting an encoding parameter. The apparatus includes means for determining a measurement of an amount of received network data relative to an amount of transmitted network data,

and means for transmitting an encoding parameter, the encoding parameter based at least in part on the determined measurement. In some aspects, the means for determining a measurement is configured to determine a ratio of the amount of received network data to the amount of transmitted network data. In other aspects, the means for determining a measurement is configured to determine a difference between the amount of received network data and the amount of transmitted network data.

In some aspects, the apparatus includes means for receiving a quantity of data transmitted by a transmitter, and means for determining the transmitted network data based at least in part on the quantity. In some aspects, the apparatus also includes means for transmitting the encoding parameter value to a transmitting node. In some aspects, the apparatus also includes means for transmitting a quantity of data received to the transmitting node. In some aspects, the apparatus also includes means for determining a network jitter, wherein the means for transmitted parameter is based at least on the network jitter.

In some aspects, the apparatus also includes means for determining if the adjustment of the encoding parameter will increase a transmission rate, and means for determining a second adjustment to a second encoding parameter that will further increase the transmission rate if the network jitter is below a first jitter threshold. In some aspects, the first and second encoding parameters are different parameters. In some aspects, the apparatus also includes means for determining if the adjustment of the encoding parameter will decrease a transmission rate, and means for determining a second adjustment to a second encoding parameter that will further decrease the transmission rate if the network jitter is above a second jitter threshold. In some aspects, the encoding parameter and the second encoding parameter are different parameters.

In some aspects, the apparatus also includes a processor configured to determine a delay in receiving the quantity of data transmitted by the transmitter, and determine the received network data based at least in part on the delay. In some aspects, the apparatus also includes a processor configured to determine a transmission rate based on the determined measurement, wherein the means for transmitting the parameter is configured to base the transmitted parameter at least in part on the transmission rate.

Another aspect disclosed is a non-transitory, computer readable storage medium comprising instructions that when executed cause a processor to perform a method of transmitting an encoding parameter. The method includes determining, via an electronic device, a measurement of an amount of received network data relative to an amount of transmitted network data, and transmitting an encoding parameter, the encoding parameter based at least in part on the determined measurement. In some aspects, the method includes receiving a quantity of data transmitted by a transmitter, and determining the transmitted network data based at least in part on the quantity. In some aspects, the method includes transmitting the encoding parameter value to a transmitter. In some aspects, the method also includes transmitting a quantity of data received to the transmitter. In some aspects, the method also includes determining a network jitter, wherein the transmitted parameter is based at least on the network jitter. In some aspects, the method also includes determining if the adjustment of the encoding parameter will increase a transmission rate, and determining a second adjustment to a second encoding parameter that will further increase the transmission rate if the network jitter is below a first jitter threshold. In some aspects, the encoding parameter and the

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second encoding parameter are different parameters. In some aspects, the method also includes determining if the adjustment of the encoding parameter will decrease a transmission rate, and determining a second adjustment to a second encoding parameter that will further decrease the transmission rate if the network jitter is above a second jitter threshold. In some aspects, the encoding parameter and the second encoding parameter are different parameters.

In some aspects, the method also includes determining a delay in receiving the quantity of data transmitted by the transmitter, and determining the received network data based at least in part on the delay. In some aspects, the method includes determining a transmission rate based on the determined measurement, wherein the transmitted parameter is based at least in part on the transmission rate.

These and other implementations consistent with the invention are further described below with reference to the following figures.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates a functional block diagram of an exemplary video encoding and decoding system.

FIG. 2 shows a functional block diagram of an exemplary multimedia processing device.

FIG. 3A illustrates a functional block diagram of an exemplary communication device.

FIG. 3B illustrates a functional block diagram of an exemplary communication device.

FIG. 4 illustrates one embodiment of a receiver report 400.

FIG. 5A illustrates a process flow diagram for a method of encoding multimedia information.

FIG. 5B is a functional block diagram of an exemplary device 550.

FIG. 5C is an example of a timing diagram illustrating the correlation of transmitting information with receiving information.

FIG. 6A illustrates a process flow diagram for a method of encoding multimedia information.

FIG. 6B is a functional block diagram of an exemplary device 650.

FIG. 6C illustrates a transmission rate and a reception rate.

FIG. 7 illustrates a transmission rate of a transmitter over time that is implementing at least one of the operative embodiments.

FIG. 8A illustrates a process flow diagram for a method of determining a network round trip time.

FIG. 8B is a functional block diagram of an exemplary device 850.

FIG. 8C is a sequence diagram illustrating messages transmitted and received in one embodiment of a method of determining a network round trip time.

FIG. 9A illustrates a process flow diagram for a method of determining a network queue drain duration.

FIG. 9B is a functional block diagram of an exemplary device 950.

FIG. 10A is a graph illustrating the relationship between a transmission and reception rate.

FIG. 10B is a graph illustrating one-way network delay.

FIG. 11A illustrates a process flow diagram for a method of determining a one way network transmission delay.

FIG. 11B is a functional block diagram of an exemplary device 1150. In the figures, to the extent possible, elements having the same or similar functions have the same designations.

FIG. 12 illustrates one embodiment of a transmitter report 1200.

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FIG. 13A illustrates a process flow diagram for a method of determining an encoding parameter.

FIG. 13B is a functional block diagram of an exemplary device 1350.

FIG. 13C is an example of a timing diagram illustrating the correlation of transmitting information with receiving information.

FIG. 14A illustrates a process flow diagram for a method of determining an encoding parameter.

FIG. 14B is a functional block diagram of an exemplary device 1450.

FIG. 15A illustrates a process flow diagram for a method of determining encoding parameters.

FIG. 15B is a functional block diagram of an exemplary device 1550.

FIG. 16A illustrates a process flow diagram for a method of determining an encoding parameter based on a network jitter.

FIG. 16B is a functional block diagram of an exemplary device 1650.

DETAILED DESCRIPTION

Because network capacity may be variable and unpredictable, it may be desirable to vary a transmission rate to match a current network capacity. Without such adaptation, users may experience substantial or prolonged artifacts due to packet losses and latencies. In some embodiments, this may result in jitter or delays in the playback of multi-media data. Described herein are methods, apparatus, and computer readable media that provide for dynamic adaptation of transmission rates based on time-varying network conditions to provide for an improved user experience. In some embodiments, transmission rates may be modified by altering one or more encoding parameters of an encoder that is transmitting multimedia data onto the network.

In the following description, specific details are given to provide a thorough understanding of the examples. However, it will be understood by one of ordinary skill in the art that the examples may be practiced without these specific details. For example, electrical components/devices may be shown in block diagrams in order not to obscure the examples in unnecessary detail. In other instances, such components, other structures and techniques may be shown in detail to further explain the examples.

It is also noted that the examples may be described as a process, which is depicted as a flowchart, a flow diagram, a finite state diagram, a structure diagram, or a block diagram. Although a flowchart may describe the operations as a sequential process, many of the operations can be performed in parallel, or concurrently, and the process can be repeated. In addition, the order of the operations may be re-arranged. A process is terminated when its operations are completed. A process may correspond to a method, a function, a procedure, a subroutine, a subprogram, etc. When a process corresponds to a software function, its termination corresponds to a return of the function to the calling function or the main function.

Those of skill in the art will understand that information and signals may be represented using any of a variety of different technologies and techniques. For example, data, instructions, commands, information, signals, bits, symbols, and chips that may be referenced throughout the above description may be represented by voltages, currents, electromagnetic waves, magnetic fields or particles, optical fields or particles, or any combination thereof.

Various aspects of embodiments within the scope of the appended claims are described below. It should be apparent that the aspects described herein may be embodied in a wide

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variety of forms and that any specific structure and/or function described herein is merely illustrative. Based on the present disclosure one skilled in the art should appreciate that an aspect described herein may be implemented independently of any other aspects and that two or more of these aspects may be combined in various ways. For example, an apparatus may be implemented and/or a method may be practiced using any number of the aspects set forth herein. In addition, such an apparatus may be implemented and/or such a method may be practiced using other structure and/or functionality in addition to or other than one or more of the aspects set forth herein.

Disclosed herein are methods, apparatus, and computer readable media that adapt a transmission rate based on network conditions between a transmitter and a receiver. Because network conditions may vary, dynamic adaptation of the transmission rate may provide an improved user experience when compared to a statically determined transmission or encoding rate.

In designing a system that provides for adaptive transmission rates, at least two design approaches can be considered. First, a model-based or closed-form approach may be utilized. In such an approach, a channel is modeled for certain variables, such as bandwidth, by using a fixed or closed mathematical form. The model is parameterized with unknowns that may be derived by experimentation. The encoder output may also be modeled similarly and perform in synchronization with the channel model.

Another approach is a state based or “fuzzy” approach. Such an approach may be token-based, in that network statistics are periodically gathered and provided to a decision engine that derives an expected network state. Such a state then determines a course of action taken by the system. This may include maintaining the current operational mode of the transmitter, or modifying transmitter parameters to either increase or decrease the rate at which data is transmitted into the network. In an embodiment, the transmitter may alter a bit rate in fixed quanta that span a pre-determined range from a minimum to a maximum quanta.

The advantages of a heuristic channel-state based approach may include acceptable margins, robustness in the face of false positives, and a stable output. Since the model is based on network states governed by acceptable margins for network statistics, the system is less sensitive to imprecision and/or deviations incurred by the measurement of network variables. Furthermore, since the system is token based, spurious deviation of network variables may not cause substantial deviations in derived encoder parameters. Updates to transmitter parameters may occur based on a token count (or a combination of token counts pertaining to separate network variables) exceeding one or more thresholds. This characteristic of the system may provide a level of insulation from spurious indications. Additionally, it may be desirable to provide a minimum duration of time between updates to one or more transmitter parameters. This minimum duration of time provides an opportunity for the transmitter to converge to a selected set of parameter values. This may lead to a more predictable encoder output and reduce the possibility of the transmitter output deviating substantially from specified parameters. The quantized aspects of the system help provide for this minimum duration of time between updates to one or more transmitter or encoder parameters.

One disclosed embodiment may derive a transmission rate $R_v(t)$ at time “t” as a mapping of three network variables:

$$R_v(t) = \text{map}(R_f(t), D_f(t), L_f(t)) \quad (1)$$

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where:

$R_f(t)$ is a measured forward (sender-to-receiver) throughput

$D_f(t)$ is a measured forward (sender-to-receiver) packet delay, and

$L_f(t)$ is a measured forward (sender-to-receiver) packet loss

FIG. 1 illustrates a functional block diagram of an exemplary video encoding and decoding system. As shown in FIG. 1, system 10 includes a source device 12 that may be configured to transmit encoded multimedia data to a destination device 16 via a communication channel 15. Source device 12 and destination device 16 may comprise any of a wide range of devices, including mobile devices or generally fixed devices. In some cases, source device 12 and destination device 16 comprise wireless communication devices, such as wireless handsets, so-called cellular or satellite radiotelephones, personal digital assistants (PDAs), mobile media players, or any devices that can communicate video information over a communication channel 15, which may or may not be wireless. However, the techniques of this disclosure, which concern adapting one or more parameters of the encoder 22, may be used in many different systems and settings. FIG. 1 is merely one example of such a system.

In the example of FIG. 1, the source device 12 may include a multimedia source 20, a multimedia encoder 22, a modulator/demodulator (modem) 23 and a transmitter 24. Destination device 16 may include a receiver 26, a modem 27, a multimedia decoder 28, and a multimedia player 30. In accordance with this disclosure, multimedia encoder 22 of source device 12 may be configured to encode multimedia data. Modem 23 and transmitter 24 may modulate and transmit wireless signals to destination device 16. In this way, source device 12 communicates the encoded multimedia data to destination device 16.

Receiver 26 and modem 27 receive and demodulate wireless signals received from source device 12. Accordingly, multimedia decoder 28 may receive the transmitted multimedia data.

Source device 12 and destination device 16 are merely examples of such coding devices in which source device 12 generates coded multimedia data for transmission to destination device 16. In some cases, devices 12 and 16 may operate in a substantially symmetrical manner such that, each of devices 12 and 16 includes multimedia sources/sinks, encoding/decoding components, modulators/demodulators and transmitters/receivers. Hence, system 10 may support one-way or two-way multimedia transmission between multimedia devices 12 and 16. Source device 12 may also communicate with other destination devices (not shown) in addition to destination device 16 to perform one or more concurrent conversations with multiple destination devices. e.g., for multimedia streaming, multimedia broadcasting, or multimedia telephony.

Multimedia source 20 of source device 12 may include a multimedia capture device, such as a microphone, video camera, an audio or video archive containing previously captured audio or video, or an audio or video feed from a content provider.

The encoded multimedia information may then be modulated by a modem 23 according to a communication standard, e.g., such as code division multiple access (CDMA) or another communication standard, and transmitted to destination device 16 via transmitter 24. The modem 23 may include various mixers, filters, amplifiers or other components designed for signal modulation. The transmitter 24 may include circuits designed for transmitting data, including amplifiers, filters, and one or more antennas.

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Receiver **26** of destination device **16** may be configured to receive information over channel **15**. A modem **27** may be configured to demodulate the information. The multimedia encoding process may implement one or more of the techniques described herein. The information communicated over channel **15** may include information defined by multimedia encoder **22**, which may be used by multimedia decoder **28** consistent with this disclosure. The multimedia player **30** may play a selective subset or all of the decoded multimedia data to a user, and may comprise any of a variety of players such as an audio or video player, or a video telephony player.

In the example of FIG. 1, communication channel **15** may comprise any wireless or wired communication medium, such as a radio frequency (RF) spectrum or one or more physical transmission lines, or any combination of wireless and wired media. Accordingly, modem **23** and transmitter **24** may support many possible wireless protocols, wired protocols or wired and wireless protocols. Communication channel **15** may form part of a packet-based network, such as a local area network (LAN), a wide-area network (WAN), or a global network, such as the Internet, comprising an interconnection of one or more networks. Communication channel **15** generally represents any suitable communication medium, or collection of different communication media, for transmitting video data from source device **12** to destination device **16**. Communication channel **15** may include routers, switches, base stations, or any other equipment that may be useful to facilitate communication from source device **12** to destination device **16**. The techniques of this disclosure do not necessarily require communication of encoded data from one device to another, and may apply to encoding scenarios without the reciprocal decoding. Also, aspects of this disclosure may apply to decoding scenarios without the reciprocal encoding.

Multimedia encoder **22** and multimedia decoder **28** may operate consistent with a compression standard, such as the ITU-T H.264 standard, alternatively described as MPEG-4, Part 10, and Advanced Video Coding (AVC), or the next-generation video coding standard named High Efficiency Video Coding (HEVC). The techniques of this disclosure, however, are not limited to any particular coding standard or extensions thereof. Although not shown in FIG. 1, in some aspects, multimedia encoder **22** and multimedia decoder **28** may include both a video and audio encoder and a video and audio decoder, and may include appropriate MUX-DEMUX units, or other hardware and software, to handle encoding of both audio and video in a common data stream or separate data streams. If applicable, MUX-DEMUX units may conform to a multiplexer protocol (e.g., ITU H.223) or other protocols such as the user datagram protocol (UDP).

Multimedia encoder **22** and multimedia decoder **28** each may be implemented as one or more microprocessors, digital signal processors (DSPs), application specific integrated circuits (ASICs), field programmable gate arrays (FPGAs), discrete logic circuitry, software executing on a microprocessor or other platform, hardware, firmware or any combinations thereof. Each of multimedia encoder **22** and multimedia decoder **28** may be included in one or more encoders or decoders, either of which may be integrated as part of a combined encoder/decoder (CODEC) in a respective mobile device, subscriber device, broadcast device, server, or the like.

FIG. 2 shows a functional block diagram of an exemplary multimedia processing device. The device **202** is an example of a device that may be configured to implement the various

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methods described herein. For example, the device **202** may be implemented as the source device **12** or the destination device **16**.

The device **202** may include processor unit(s) **204** which control operation of the device **202**. One or more of the processor unit(s) **204** may be collectively referred to as a central processing unit (CPU). Memory **206**, which may include both read-only memory (ROM) and random access memory (RAM), provides instructions and data to the processor units **204**. The memory **206** may generally be implemented as a computer readable storage medium. A portion of the memory **206** may also include non-volatile random access memory (NVRAM). The processor unit(s) **204** may be configured to perform logical and arithmetic operations based on program instructions stored within the memory **206**. The instructions in the memory **206** may be executable to implement the methods described herein.

The processor unit(s) **204** may be implemented with any combination of general-purpose microprocessors, microcontrollers, digital signal processors (DSPs), field programmable gate array (FPGAs), programmable logic devices (PLDs), controllers, state machines, gated logic, discrete hardware components, dedicated hardware finite state machines, or any other suitable entities that can perform calculations or other manipulations of information. In an implementation where the processor unit(s) **204** include a DSP, the DSP may be configured to generate a packet (e.g., a data packet) for transmission. In some aspects, the packet may comprise a physical layer data unit (PPDU).

The device **202** may also include machine-readable media for storing software. The processing unit(s) **204** may comprise one or more non-transitory machine-readable media for storing software. Software shall be construed broadly to mean any type of instructions, whether referred to as software, firmware, middleware, microcode, hardware description language, or otherwise. Instructions may include code (e.g., in source code format, binary code format, executable code format, or any other suitable format of code). The instructions, when executed by the processor unit(s) **204**, cause the device **202** to perform the various functions described herein.

The device **202** may include a transmitter **210** and/or a receiver **212** to allow transmission and reception, respectively, of data between the device **202** and a remote location. The transmitter **210** and receiver **212** may be combined into a transceiver **214**. An antenna **216** may be attached to the housing **208** and electrically coupled with the transceiver **214**. The device **202** may also include (not shown) multiple transmitters, multiple receivers, multiple transceivers, and/or multiple antennas.

The transmitter **210** may be configured to wirelessly transmit packets and/or signals. For example, the transmitter **210** may be configured to transmit different types of packets generated by the processor unit(s) **204**, discussed above. The packets to be transmitted are provided to the transmitter **210**. For example, the processor unit(s) **204** may store a packet in the memory **206** and the transmitter **210** may be configured to retrieve the packet. Once the transmitter retrieves the packet, the transmitter **210** transmits the packet to via the antenna **216**. In some implementations, the transmitter **210** may transmit the packet via a network input/output **224**.

If the device **202** is implemented as a destination device **16**, the antenna **216** detects wirelessly transmitted packets/signals. The receiver **212** may be configured to process the detected packets/signals and make them available to the processor unit(s) **204**. For example, the receiver **212** may store the packet in memory **206** and the processor unit(s) **204** may be configured to retrieve the packet.

The device **202** may also include a signal detector **218** that may be used in an effort to detect and quantify the level of signals received by the transceiver **214**. The device **202** may also include a digital signal processor (DSP) **220** for use in processing signals. The DSP **220** may be configured to generate a packet for transmission or receive a packet from the receiver **212**. In some aspects, the packet may comprise a physical layer data unit (PPDU).

The device **202** may further comprise a user interface **222** in some aspects. The user interface **222** may comprise a keypad, a microphone, a speaker, and/or a display. In some implementations, the device **202** may be coupled with a display. For example, the device **202** may be implemented as a set-top-box which receives video information, processes the information for display, and transmit the information to a television for display. The user interface **222** may further include any element or component that conveys information to a user of the device **202** and/or receives input from the user. The device **202** may also include a housing **208** surrounding one or more of the components included in the device **202**.

The various components of the device **202** may be coupled together by a bus system **226**. The bus system **226** may include a data bus, for example, as well as a power bus, a control signal bus, and a status signal bus in addition to the data bus. Those of skill in the art will appreciate the components of the device **202** may be coupled together or accept or provide inputs to each other using some other mechanism.

Although a number of separate components are illustrated in FIG. 2, those of skill in the art will recognize that one or more of the components may be combined or commonly implemented. For example, the processor unit(s) **204** may be used to implement not only the functionality described above with respect to the processor unit(s) **204**, but also to implement the functionality described above with respect to the signal detector **218**. Further, each of the components illustrated in FIG. 2 may be implemented using a plurality of separate elements.

FIG. 3A illustrates a functional block diagram of an exemplary communication device **300**. In an embodiment, the communication device **300** may be implemented as wireless device **202** of FIG. 2. The communication device **300** includes an encoder **302**, encoder parameter manager **304**, and a report processor **306**. The encoder **302** receives at least two inputs: unencoded multimedia information and encoder parameters. The unencoded multimedia data may be provided to the encoder **302** directly or indirectly by one or more multimedia applications (not shown). The encoder **302** may also receive one or more encoder parameters from encoder parameter manager **304**. The encode parameters may identify an encoding scheme to be applied. The encoder parameters may be dynamic and provided for each multimedia stream or for each portion of a multimedia stream.

The encoder **302** may be configured to apply the configured encoding scheme to multimedia data when generating an encoded version of the multimedia data. In some implementations, the encoded version of the multimedia data may be provided to a transmitter for transmission as discussed above. In some implementations, the encoded version of the multimedia data may be further processed by the source device **12** (e.g., encrypted, compressed).

The encoder parameter manager **304** determines encoding parameters to send to the encoder **302**. The encoder parameters may be selected based at least in part on the multimedia information, one or more characteristics of the source device **12** (e.g., power, processing capabilities, load), one or more characteristics of the destination device (e.g., power, processing capabilities, load, coupling with source device), one or

more characteristics of the network, and/or other information available to the source device **12**. Aspects of determining encoding parameters by the encoder parameter manager **304** are discussed herein. In some aspects, the encoder parameter manager **304** also receives suggested encoding parameters from a receiver, for example, device **350** discussed below with respect to FIG. 3B. In some other aspects, no suggested encoding parameters are received from a receiver.

In an embodiment, the encoder parameters are determined based, at least in part, on bandwidth, throughput, delay, and loss information provided by the report processor **306**. The encoder parameters may include an encoding bit rate. Encoder parameters may also include temporal adaptation parameters, spatial adaptation parameters, and error resiliency parameters. Error resiliency parameters may include a group of pictures (GOP) size, and/or parameters to control dynamic insertion of refresh frames, for example, in H.264 encoding. Error resiliency parameters may include dynamic slice configuration parameters and/or a dynamic application of temporal scalability.

The report processor **306** sends one or more of bandwidth information, delay information, and loss information to the encoder parameter manager **304**. In an embodiment, the report processor **306** receives receiver reports from a receiver of the encoded multimedia data. One embodiment of a receiver report is shown in FIG. 4.

FIG. 3B illustrates a functional block diagram of an exemplary communication device **350**. In an embodiment, the communication device **350** may be implemented as wireless device **202** of FIG. 2. The communication device **350** includes a decoder **352**, encoder parameter manager **354**, and a report processor **356**. The decoder **352** receives encoded multimedia data from an encoder, for example encoder **302**. The decoder decodes the encoded multimedia data and outputs decoded multimedia data. The decoder may also send decoder and/or receiver statistical information to the encoder parameter manager **354**.

The encoder parameter manager **354** determines encoding parameters to send to an encoder. For example, the encoder parameter manager **354** may send encoding parameters to device **300**. The encoder parameters may be selected based at least in part on the decoded multimedia information, one or more characteristics of the source device **12** (e.g., power, processing capabilities, load), one or more characteristics of the destination device (e.g., power, processing capabilities, load, coupling with source device), one or more characteristics of the network, and/or other information available to the destination device **16**. Aspects of determining encoding parameters by the encoder parameter manager **354** are discussed herein.

In an embodiment, the encoder parameters are determined based, at least in part, on bandwidth, throughput, delay, and loss information provided by the report processor **356**. The encoder parameters may include an encoding bit rate. Encoder parameters may also include temporal adaptation parameters, spatial adaptation parameters, and error resiliency parameters. Error resiliency parameters may include a group of pictures (GOP) size, and/or parameters to control dynamic insertion of refresh frames, for example, in H.264 encoding. Error resiliency parameters may include dynamic slice configuration parameters and/or a dynamic application of temporal scalability.

The report processor **356** sends one or more of bandwidth information, delay information, and loss information to the encoder parameter manager **354**. In an embodiment, the report processor **356** receives transmitter reports from a trans-

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mitter of the encoded multimedia data. One embodiment of a transmitter report is shown in FIG. 12.

FIG. 4 illustrates one embodiment of a receiver report 400. The receiver report 400 includes data fields that may be utilized for achieving encoder adaptation. In an embodiment, these fields may be derived from a custom feedback structure, such as an RTP-extension. In an embodiment, the fields may be derived from a RTCP AVP and/or AVPF standard structures.

To dynamically adapt encoder parameters as described above based on conditions of a network between a transmitter and a receiver, a feedback loop between the transmitter and the receiver may be established. This feedback loop may utilize receiver reports to communicate information on received data to the transmitter. In an embodiment, receiver reports may be transmitted to the transmitter at a periodic interval, which may be configurable. In an embodiment, receiver reports may be event-triggered. For example, receiver reports may be transmitted when changes to one or more network conditions cross one or more predetermined thresholds. The size and structure of the receiver report, such as the number of fields, size of the fields, or the type of the fields, may vary from that shown in FIG. 4, and may also vary based on the network statistics being reported. In some embodiments, receiver reports may piggy-back on other network communication packets between the transmitter and the receiver. For example, in an embodiment utilizing the Real Time Protocol (RTP), receiver reports may be appended as a custom RTP extension payload format for video packets.

In some embodiments, receiver reports may be structured and communicated using the RTCP AVP and/or AVPF standards. For example, in an embodiment utilizing RTCP AVPF feedback protocols, the above information may be derived from a combination of fields in the Regular/Immediate mode RTCP Sender/Receiver Reports, Generic NACK, Picture Loss Indication (PLI), TMMBR/TMMBN tuples and Full Intra Request (FIR) messages.

The fields of the receiver report 400 may refer to a context of the transmitter of the receive report. The receiver report 400 may include a far tag time received field 405. The far tag time received field 405 may have been previously received by the transmitter of the receiver report 400. The receive report 400 also includes a duration held tag time 410. In an embodiment, the duration held tag time field 410 indicates a duration of time between when the far tag time provided in field 405 was received and the receiver report was transmitted. The receive report 400 also includes a near tag time sent field 415. In some embodiments, the near tag time sent field 415 will be returned as the far tag time received field 405, contained in a receiver report originating from a device receiving receive report 400. In some embodiments, the receiver of the receive report 400 is expected to transmit the near tag time field 415 back to the transmitter of the receive report. The receive report 400 also includes a cumulative receive count field 420. In one embodiment, the cumulative receive count field 420 indicates a cumulative number of received messages received by the receiver. In an embodiment, the cumulative receive count field 420 indicates a cumulative number of received packets received by the receiver. The receive report 400 also includes a cumulative loss count field 425. The cumulative loss count 425 indicates a cumulative number of lost messages or packets detected by the receiver generating the receiver report 400. The receive report 400 further includes a cumulative AU count field 430. The cumulative AU count field 430 indicates the cumulative number of video access units received by this receiver. The receiver report 400 further includes two cumulative bytes received fields 435 (high order

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bits) and 440 (low order bits). The cumulative bytes received fields 435 and 440 indicate a total number of bytes received within a network communication channel by the receiver sending the receive report 400. The receiver report 400 also includes an AU metadata field 445. The AU metadata field indicates frame information. In an embodiment, receiver reports may vary in size depending on whether they only carry delay related information, known as short receive reports, or if they also include network throughput and loss statistics, known as full receive reports.

As shown, the receiver report contains aggregate byte counts and receiver time-line information. Information contained in a receiver report may be used to calculate a moving average reception rate, $R_f(t)$, which is used as an indicator of throughput. In an embodiment, $R_f(t)$ may represent a rate in kilobits per second. In one embodiment, $R_f(t)$ may be derived as a rectangular moving average as:

$$R_f(t) = \frac{\left(\int_{t-\Delta t}^t b(t) \right)}{\Delta t} \Big|_{\Delta t \geq \Delta t_f; R_v = K \text{ (Constant)}} \quad (2)$$

where:

$b(t)$ is the bytes received at time t on a receiver clock

Δt is an interval for calculating an average

Δt_f is a minimum interval for a reliable average, and

R_v is the current transmitting rate

The interval Δt_f should be determined to ensure a reliable average that is robust to network jitter. To provide for an ability to adapt to a drop in network throughput within an acceptable timeframe, receiver reports providing byte counts and timing information used in calculating a throughput may be provided at a finer resolution than Δt_f , denoted as Δt_{rr} , where $\Delta t_{rr} \ll \Delta t_f$. In an embodiment, a transmitter may store previously received receiver reports. The transmitter may search the stored receiver reports for a most recent report such that $\Delta t \geq \Delta t_f$ at a static encoding rate R_v .

The throughput estimate may be improved by use of an averaging strategy to smooth network jitter. In an embodiment, a single-tap (LP) infinite impulse response (IIR) filter may be employed as:

$$R'_f(t_n) = \beta \cdot R'_f(t_{n-1}) + (1-\beta) \cdot R_f(t_n) \quad (3)$$

where:

$R'_f(t_k)$ is the one-tap IIR average throughput estimate at time t_k ($k=n, n-1$)

$R_f(t_n)$ is the rectangular moving average throughput calculation for the current instant t_n

The calculated throughput above includes a delay $D_r(t_n)$ which may be composed of delays introduced when a receiver report is transmitted, and then received and parsed by the transmitter. Because of this delay, $R'_f(t_n)$ refers to a throughput estimate at the receiver as observed at time $(t_n - D_r(t_n))$ on the transmitter's clock. To use the calculated throughput, a consumption to production measurement is determined. This measurement will generally not fall below a threshold for a given number of tokens. This measurement is discussed in more detail with respect to FIG. 5.

FIG. 5A illustrates a process flow diagram for a method of encoding multimedia information. In an embodiment, process 500 may be performed by the wireless device 202 illustrated in FIG. 2. In processing block 505, a measurement of an amount of received network data relative to an amount of transmitted network data is determined via an electronic device. In some aspects, the measurement may be a ratio of

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received network data to transmitted network data. In an embodiment, the ratio may be calculated as:

$$\rho(t_n) = R'_f(t_n) / R_v(t_n) \quad (4)$$

where:

t_n is a time n at a transmitting node

$R_v(t_n)$ is an encoding rate at time n

$R'_f(t_n)$ is a receiving rate at time n

In an embodiment, a transmitter may maintain a record of an encoding or transmitting rate over time. For example, an embodiment may define a duration of time during which an amount of data encoded or transmitted is accumulated and recorded. When the duration of time has expired, a second time period may begin, with the amount of data encoded or transmitted during the second time period accumulated and recorded. This process repeats, resulting in a series of recorded encoding or transmitting rates, representing an amount of data encoded over each successive time period.

In an embodiment, the receiving rate, such as $R'_f(t_n)$, may be determined based on a report received from a receiver, such as the receiver report described with respect to FIG. 4. In an embodiment, receiver reports may be received periodically. In an embodiment, the transmission of receiver reports may be event-triggered. In an embodiment, both event-triggered and periodic receive reports may be transmitted. In an embodiment, the frequency with which receiver reports are received may be correlated with the frequency with which the encoding rates are accumulated and stored as discussed above. In another embodiment, the frequency of receiver reports may be uncorrelated with the frequency at which encoding or transmitting information is accumulated.

In an embodiment, the ratio of received network data to transmitted network data may be based on a receiving rate and a transmission rate correlated in time as discussed above. For example, the rates used to determine the ratio may be delay adjusted moving average rates. In some embodiments, the transmitting rates and receiving rates may be correlated by adjusting the receiving rate information based on a delay. For example, receiving information may be transmitted by a receiver in a receiver report to a transmitter. The receiver report may be received by the transmitter after a delay period caused by at least network delays and delays associated with the receiver assembling and packaging the receiving information for transmission to the transmitter. Because the transmitter and receiver may not share a common clock, it may not be possible to correlate transmitting information and receiving information based on a timestamp or other absolute timing information. Instead, estimate determined delay from when receiving information is collected to when the receiving information is received by the transmitter may be used to correlate the receiving information with transmitting information. In an embodiment, the delay may be determined in a manner substantially in accordance with process 1100, illustrated in FIG. 11. By correlating an encoding rate and a receiving rate for a single time period, the ratio more accurately reflects the relationship between consumption and production during the single time period.

The ratio, in an embodiment $\rho(t_n)$, may provide an indication of network conditions between a transmitter and a receiver. For example, if the ratio is approximately one (1), this may indicate that a rate of transmission at a time t_n minus a delay $D_r(t_n)$ was sustainable. In some embodiments, a ratio within a distance α from one (1) may also be considered to indicate sustainable network conditions. A ratio of approximately one (1) or one $(1) \pm \alpha$ does not necessarily indicate 100% channel utilization.

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If the ratio is less than one, or less than $(1-\alpha)$ as described above, it may indicate a current encoding or transmission rate, for example, $R_v(t_n)$ in an embodiment utilizing equation (1), is not sustainable. To verify a low ratio indicates a transmission rate is not sustainable, a transmitter may maintain a record of transmitter or encoder delay-adjusted moving average output rates, for example, $\{r_v(t_n), r_v(t_{n-1}), r_v(t_{n-2}), \dots\}$. The ratio may then be calculated as:

$$\rho(t_n) = R'_f(t_n) / r_v(t_n) \quad (5)$$

where:

t_n is a transmitter instant in time when receiver report 'n' is received

$R'_f(t_n)$ is the one-tap IIR average throughput estimate at time t_n (from equation (3))

$r_v(t_n)$ is measured over the interval $[t_{n-1} - D_R(t_{n-1}), t_n - D_R(t_n)]$, and

$D_R(t_n)$ is an average reverse direction delay for receiver report arrival at time t_n

If the ratio is greater than one, or greater than one $(1) + \alpha$ as described above, it may indicate that buffered data in the network is being received at a rate higher than new data is being encoded and sent over the network. A ratio greater than one may be experienced after a network recovers from a period of reduced throughput. During the period of reduced throughput, transmission of data by a data source into the network based on an encoding rate may exceed a capacity of the network to transfer data to the receiver. Some of this excess data may be buffered, and some of the excess data may be dropped. When the network recovers and throughput of the network increases, the buffered data in the network may be sent to the receiver. This data may be received by the receiver at a rate that exceeds the transmission rate.

At block 510, an encoding parameter is adjusted based on the determined measurement. Encoding parameters adjusted based on the measurement may include bit rate parameters, temporal adaptation parameters, spatial adaptation parameters, or error resiliency parameters, as discussed previously. In an embodiment, if the determined measurement is a ratio, and the ratio is less than one, or $(1 \pm \alpha)$ as described above, one or more encoding parameters may be adjusted to reduce the size of encoded multimedia data generated by an encoder. In an embodiment, encoding parameters may be adjusted to render encoded data more resilient to errors if the determined ratio is less than one, or less than $(1 \pm \alpha)$. For example, the encoding bit rate may be reduced if the determined measurement is less than one, or $(1 \pm \alpha)$ as described above. In an embodiment, the encoding bit rate may be increased if a predetermined number of sequential ratios are more than one, or $(1 \pm \alpha)$ as described above.

In an embodiment, an encoding parameter may not be adjusted until a sequential threshold number F_p of ratios are determined to be less than one (1) or $(1-\alpha)$. For example, if a ratio is determined for each sequential token or quanta, a predetermined number F_p of sequential tokens having a ratio less than $(1-\alpha)$ may be necessary before an encoding parameter is adjusted. This may avoid over reacting to spurious deviations in network state.

In an embodiment, an encoding parameter may be adjusted when fewer than F_p sequential ratios are determined to be less than $(1-\alpha)$ and a forward link delay estimate is above a second threshold, for example, denoted as $D_F(t_n) \geq D_F^U$.

In an embodiment, the receiver side throughput influence on a transmission rate may be expressed with the following Boolean functional:

$$B(R_v(t_n+1) < (R_v(t_n))) = \{ \rho(t_n) < (1-\alpha) \& f_p \geq F_p \} \cup \{ \rho(t_n) < (1-\alpha) \& D_F(t_n) \geq D_F^U \} \quad (6)$$

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where:

t_n is a transmitter time instant when a receiver report 'n' is received

$R_v(t_n)$ is an encoding rate at time instant t_n

$\rho(t_n)$ is the ratio of received network data to transmitted network data (eq (5))

f_p is a number of sequential determined ratios indicating low throughput

F_p is a threshold number of sequential determined ratios indicating low-throughput

$D_F(t_n)$ is a forward-path delay estimate at transmitter time instant t_n , and

D_F^U is a forward-path high delay threshold

Note that while in the embodiment discussed above, some transmission or encoding adjustments are performed when the ratio is less than one or less than $(1-\alpha)$, it should be understood that other embodiments may determine a ratio that is the inverse of the ratio disclosed in the embodiment above. In these other embodiments, adjustments to transmission or encoding parameters may be performed in an opposite manner as those described above. For example, in these embodiments, if the determined ratio is more than one, or $(1\pm\alpha)$, one or more encoding parameters may be adjusted to reduce the size of encoded multimedia data generated by an encoder. In an embodiment, encoding parameters may be adjusted to render encoded data more resilient to errors if the determined ratio is more than one, or more than $(1+\alpha)$. For example, the encoding bit rate may be reduced if the determined ratio is more than one, or $(1+\alpha)$ as described above. In an embodiment, the encoding bit rate may be increased if a predetermined number of sequential ratios are less than one, or $(1-\alpha)$. FIG. 5B is a functional block diagram of an exemplary device 550. In an embodiment, device 550 may be implemented as wireless device 202, illustrated in FIG. 2. The device 550 includes means 560 for determining, via an electronic device, a measurement of an amount of received network data relative to an amount of transmitted network data. In an embodiment, means 560 may be configured to perform one or more of the functions discussed above with respect to block 505. The means for determining a measurement 560 may include a processor, such as processor 204 of FIG. 2. Means 560 may also include one or more of a signal generator, transceiver, decoder, or a combination of hardware and/or software component(s), circuits, and/or module(s). The device 550 further includes means 565 for adjusting an encoding parameter based on the determined measurement. In an embodiment, means 565 may be configured to perform one or more of the functions discussed above with respect to block 510. The means 565 for adjusting an encoding parameter based on the determined ratio may include a processor, such as processor 204 of FIG. 2. Means 565 may also include one or more of a processor, signal generator, transceiver, decoder, or a combination of hardware and/or software component(s), circuits, and/or module(s).

FIG. 5C is a timing diagram illustrating the correlation of transmitting information with receiving information. FIG. 5C shows a transmitter 570, receiver 580, and a correlator 575. In an embodiment, any of the transmitter 570, correlator 575, or receiver 580 may be implemented by the wireless device 202, illustrated in FIG. 2. As shown in FIG. 5C, the transmitter 570 generates transmitting information periodically. FIG. 5C shows transmitting information 585a-d generated at times T_{0-3} respectively. Receiver 580 is shown transmitting receiver reports 587a-d to correlator 575. These receiving reports are generated by the receiver 580 at times $T_{0'-3'}$ respectively. Because of at least network delays, receiving reports 587a-d are received by the correlator 575 at times $T_{0''-3''}$ respectively.

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Based on a network delay, correlator 575 may correlate the transmitting information 585a-d with receiving information 586a-d. This is shown in FIG. 5C as the dashed arrows associating receiving information 586a-d with transmitting information 585a-d. In an embodiment, correlator 575 and transmitter 570 may be implemented in the same wireless device.

FIG. 6A illustrates a process flow diagram for a method of encoding multimedia information. In an embodiment, process 600 may be performed by the wireless device 202 illustrated in FIG. 2. In processing block 605, an amount of data buffered in a network is determined.

In an embodiment, the amount of data buffered may be determined based at least in part on a period of time during which an amount of data transmitted via the network exceeded the network's capacity during the period. In an embodiment, this period of time may be determined as:

$$T_R \approx F_p \cdot \Delta t_{RR} \quad (7)$$

where:

T_R is a reaction time

F_p is a token threshold for throughput based rate reduction, and

Δt_{RR} is a receiver report interval

In an embodiment, the amount of data buffered in the network may be based at least in part on how much the amount of data transmitted exceeds the network's capacity during the time period. In an embodiment, if a transmission rate is $R_v(t_n)$, the amount the transmission rate exceeds the network's capacity at an instant in time t_n may be expressed as:

$$R_{surplus} = R_v(t_n) - R'_f(t_n) \quad (8)$$

where:

$R'_f(t_n)$ is an estimated receiver throughput at time instant t_n (see equation (3))

In an embodiment, the amount of data buffered in a network may then be determined as:

$$b_R = R_{surplus} \cdot T_R \text{ or} \quad (9)$$

$$b_R = (R_v(t_n) - R'_f(t_n)) \cdot F_p \cdot \Delta t_{RR} \quad (10)$$

In processing block 610, a sustainable throughput of the network is determined. In an embodiment, the sustainable throughput may be based, at least in part, on a margin of safety. The margin of safety may be determined so as to provide an opportunity for data buffered during a period of reduced network capacity (for example, due to network congestion or hardware failure) to complete transmission after the network's capacity improves. In some embodiments, the margin of safety may be based, at least in part, on a percentage of a determined network capacity. For example, in an embodiment, ten percent of a determined network capacity may be reserved to provide an excess capacity.

In block 615, a transmission rate is determined based on the sustainable throughput and the amount of data buffered. In an embodiment, the transmission rate should be determined such that the amount of data buffered in a network is eliminated or drained within a time period t_R . In some environments, a value of one second for time period t_R provides good results. In an embodiment, the transmission rate may be determined as:

$$r_v(t_{n+1}) = R'_f(t_n) \cdot (1 - R_H^{\%}) - b_R \quad (11)$$

where:

$R_H^{\%}$ represents a percentage of network capacity based on the margin of safety discussed above, and

b_R represents the amount of data buffered in the network t_R is assumed to be unity (1 second)

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In an embodiment, a final rate $R_v(t_n+1)$ may be obtained by quantizing $r_v(t_n+1)$ to a value from an operational range of rates $R_v(D)$ as:

$$R_v(t_{n+1}) = \text{Quant}(R_v(D)[r_v(t_{n+1})]), \text{ where } R_v \leq r_v, \quad (12)$$

In block **620**, an encoding parameter is adjusted based on the transmission rate. Encoding parameters adjusted based on the transmission rate may include bit rate parameters, temporal adaptation parameters, spatial adaptation parameters, or error resiliency parameters, as discussed previously.

FIG. **6B** is a functional block diagram of an exemplary device **650**. In an embodiment, device **650** may be implemented as wireless device **202**, illustrated in FIG. **2**. The device **650** includes means **655** for determining an amount of data buffered in a network. In an embodiment, means **655** may be configured to perform one or more of the functions discussed above with respect to block **605**. The means for determining an amount of data buffered may include a processor, such as processor **204** of FIG. **2**. Means **655** may also include one or more of a signal generator, transceiver, decoder, or a combination of hardware and/or software component(s), circuits, and/or module(s). The device **650** further includes means **660** for determining a sustainable throughput of the network. In an embodiment, means **660** may be configured to perform one or more of the functions discussed above with respect to block **610**. The means **660** for determining an amount of data buffered in a network may include a processor, such as processor **204** of FIG. **2**. Means **660** may also include one or more of a processor, signal generator, transceiver, decoder, or a combination of hardware and/or software component(s), circuits, and/or module(s). The device **650** further includes means **665** for determining a transmission rate based on the sustainable throughput and the amount of data buffered. In an embodiment, means **665** may be configured to perform one or more of the functions discussed above with respect to block **615**. The means **665** for determining an amount of data buffered in a network may include a processor, such as processor **204** of FIG. **2**. Means **665** may also include one or more of a processor, signal generator, transceiver, decoder, or a combination of hardware and/or software component(s), circuits, and/or module(s). The device **650** further includes means **670** for adjusting an encoding parameter based on the transmission rate. In an embodiment, means **670** may be configured to perform one or more of the functions discussed above with respect to block **620**. The means **670** for adjusting an encoding parameter based on the transmission rate may include a processor, such as processor **204** of FIG. **2**. Means **670** may also include one or more of a processor, signal generator, transceiver, decoder, or a combination of hardware and/or software component(s), circuits, and/or module(s).

FIG. **6C** illustrates a transmission rate and a reception rate. As observed, the upper line "Tx" represents a transmission rate that is exceeding the receiving rate indicated by the lower line "R." Time period **690** represents at least a portion of a duration of time during which the transmission rate is exceeding the reception rate. The difference between the transmission and reception rate is represented by differences in a slope of the Tx and R lines. In an embodiment, an amount of data buffered in a network may be determined based on time period **690** and a difference between a transmission rate and a reception rate during that time.

FIG. **7** illustrates a transmission rate of a transmitter over time that is implementing at least one of the operative embodiments. FIG. **7** illustrates a network capacity **710**. In an embodiment, a transmission rate may be discounted or reduced from the network capacity **710** based on an amount of

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data buffered in the network. The amount of this reduction is represented by rate difference **750**, providing a reduced transmission rate represented by transmission rate **720**. Rate **720** may be further discounted or reduced by a margin of safety as discussed with respect to FIG. **6A**. The margin of safety is represented by rate reduction **740**. The resulting further reduced transmission rate is represented by line **730**. This further reduced transmission rate **730** may be known as a sustainable transmission rate. In an embodiment, actual transmission rates **705a-b** shown in FIG. **7** vary below the sustainable network capacity **730** but do not exceed sustainable network capacity **730**.

FIG. **8A** illustrates a process flow diagram for a method of determining a network round trip time. One challenge with reliable and accurate measurement of delay is the absence of a common clock across all elements of a network communication. Many feedback protocols require a common clock facility (for example, RTCP requires such a facility) or the use of the NTP 64-bit clock protocol. With NTP, each device communicates with an NTP server, which provides a clock time over a network connection. Obtaining real-time NTP time-stamps may provide variable and unknown latency in some networking environments. These NTP time-stamps may be unable to accurately provide time information relevant to adjusting transmission rates as a network capacity varies.

Process **800** described below determines a network round trip time via an exchange of time indicators between a transmitting and a receiving node. In an embodiment, process **800** may be performed by the wireless device **202** illustrated in FIG. **2**. In an embodiment, process **800** may be performed by a transmitting node. In some aspects, process **800** may be performed as part of one or more of processes **500** or **600**, discussed above. Process **800** may also be performed in some aspects of processes **900**, **1300**, or **1400**, discussed below.

In processing block **805**, information identifying a time is transmitted. In an embodiment, the information is a timestamp. In another embodiment, the information may be an index or other reference identifying a storage location storing a timestamp. In an embodiment, the information may be transmitted over a network to a receiving node. In block **810**, information identifying the transmitted time is received at a receive time. In an embodiment, the received information is a timestamp transmitted in block **805**. In an embodiment, the information received in block **810** is transmitted by the receiving node.

In block **815**, a network round trip time is determined based at least in part on the information and the receive time. In an embodiment, the round trip time is based at least in part on an elapsed time. The elapsed time may be determined based at least in part on a time the information was transmitted in block **805** and a time the information identifying the transmitted time is received in block **810**. For example, in an embodiment, the elapsed time may be a time the information is transmitted in block **805** subtracted from a time information is received in block **810**. In an embodiment, the round trip time may also be based on a determined response time of the receiving node. For example, the round trip time may be determined by subtracting the determined response time of the receiving node from the elapsed time.

In an embodiment, blocks **805** and **810** are performed iteratively. In this embodiment, multiple elapsed times may be determined based on the results of each iteration. In an embodiment, each of these multiple elapsed times may be adjusted based on determined response time. The network round trip time may then be determined based on the multiple elapsed times. For example, the multiple elapsed times may

be averaged to determine the network round trip time. In another embodiment, a moving average of multiple elapsed times may be determined as a network round trip time. In an embodiment, the network round trip time may be determined as the average elapsed time since a full receive report has been received. In an embodiment, process 800 may be performed by both the transmitting and receiving nodes discussed above.

In an embodiment, the determined network round trip time may be smoothed by filtering through a low pass and single-tap Infinite Impulse Response (IIR) filter. For example:

$$\Delta'_{RR}(t_{n+1}) = \beta \cdot \Delta'_{RR}(t_n) + (1 - \beta) \cdot \Delta_{RR}(t_n) \quad (13)$$

where:

$\Delta'_{RR}(t_k)$ is the one-tap IIR average throughput estimate at time t_k ($k=n, n+1$)

$\Delta_{RR}(t_n)$ is the rectangular moving average throughput calculation for the current instant

t_n

FIG. 8B is a functional block diagram of an exemplary device 850. In an embodiment, device 850 may be implemented as wireless device 202, illustrated in FIG. 2. The device 850 includes means 855 for transmitting information identifying a time. In an embodiment, means 855 may be configured to perform one or more of the functions discussed above with respect to block 805. In an embodiment, the means for transmitting information identifying a time may include a transmitter, such as transmitter 210 of FIG. 2. Means 855 may also include one or more of a processor, signal generator, transceiver, decoder, or a combination of hardware and/or software component(s), circuits, and/or module(s). The device 850 further includes means 860 for receiving information identifying the transmitted time at a receive time. In an embodiment, means 860 may be configured to perform one or more of the functions discussed above with respect to block 810. The means 860 for receiving information identifying the transmitted time may include a receiver, such as receiver 212 of FIG. 2. Means 860 may also include one or more of a processor, signal generator, transceiver, decoder, or a combination of hardware and/or software component(s), circuits, and/or module(s). The device 850 further includes means 865 for determining the network round trip time based at least in part on the information and the receive time. In an embodiment, means 865 may be configured to perform one or more of the functions discussed above with respect to block 815. In an embodiment, the means for determining the network round trip time based at least in part on the information and the receive time may include a processor, such as processor 204 of FIG. 2. Means 865 may also include one or more of a signal generator, transceiver, decoder, or a combination of hardware and/or software component(s), circuits, and/or module(s).

FIG. 8C is a sequence diagram illustrating messages transmitted and received in one embodiment of a method of determining a network round trip time. Shown are two devices 870 and 875. In an embodiment, either device 870 or device 875 may be wireless device 202 illustrated in FIG. 2. In some aspects, device 1 870 shown in FIG. 8C may perform process 800 discussed above. As shown in FIG. 8C, device 870 first sends a message 880 to device 875. Message 880 may include an indication of a time. Upon receiving the message 880, device 875 transmits a message 890 to device 870. Message 890 may include an indication of the time referenced in message 880. Device 875 introduces a delay 885 between the time message 880 is received until the time device 875 transmits message 890 to device 870. The total elapsed time experienced by device 870 from sending message 880 until message 890 is received is elapsed time 895. In an embodiment, a

round trip time may be based on elapsed time 895. In an embodiment, the round trip time may also be based on the delay 885 or an estimate of the delay 885. For example, a round trip time may be determined by subtracting the delay 885 if known or an estimate of delay 885 from elapsed time 895. In an embodiment, the sequence of messages shown in FIG. 8C may be exchanged iteratively. An estimated round trip time may then be determined based on multiple values of elapsed time 895 resulting from the iterative exchange of the messages shown in FIG. 8C. For example, the multiple values may be averaged to determine a round trip time. Note that while FIG. 8C illustrates device 870 sending message 880 to device 875 and device 875 sending message 890 to device 870, in some embodiments, the roles of the two devices may be reversed. In some embodiments, the message exchange illustrated in FIG. 8C will be performed in both directions. For example, device 870 will send message 880 to device 875, and device 875 will send message 880 to device 870. Device 875 may send a message 890 to device 870, and device 870 may send a message 890 to device 875.

FIG. 9A illustrates a process flow diagram for a method of determining a network queue drain duration. When a bandwidth constriction develops in a network, transmitting nodes may not react instantaneously. Therefore, transmitting nodes may continue to transmit at a rate higher than a reduced network capacity caused by the bandwidth constriction can support. During this period, the unsustainable transmission rate may result in the buffering of data in the network, and potentially packet loss. After the cause of the constriction is alleviated, network capacity may improve. When this occurs, the data buffered in the network may be transferred through the network to its destination. If transmission rates have been reduced due to the constriction, the amount of buffered data in the network may reduce. This process of buffered data reduction may be referred to as network drain or buffer drain. The time necessary to drain the network of buffered data may depend on a network throughput available after the constriction is alleviated. From the previous discussion above, the buffer build up in a network can be determined in an embodiment by:

$$b_R = (R_v(t_n) - R'_f(t_n)) \cdot F_p \cdot \Delta_{RR} \quad (14)$$

Therefore, the time t_d to drain b_R in this embodiment can be represented as:

$$\int_0^{t_d} (B(t) - r_v(t)) dt = b_R \quad (15)$$

Another embodiment is represented by process 900. In an embodiment, process 900 may be performed by the wireless device 202 illustrated in FIG. 2. In processing block 905 a measurement of an amount of received network data relative to an amount of transmitted network data is determined. In an embodiment, the measurement may be a ratio of received network data to transmitted network data. In some aspects, block 905 may be performed substantially in conformance with the description of block 505, discussed above with respect to FIG. 5A. In an embodiment, when the ratio is greater than one, or $(1 + \alpha)$, the amount of data being removed from the network (by being received) is greater than the amount of data being added to the network (by being transmitted). When this occurs, the network may be said to be "draining," in that excess data is being removed from the network. For example, packets buffered in one or more network devices along a network path between a transmitter and a receiver may move along the network path and eventually be received by the receiver, thus removing them from the network. If the received packets are not replaced, via transmission of new packets, at the rate at which they are received, the

ratio may be greater than one. In an embodiment, the size of the ratio may represent how quickly the network is draining. For example, a network with a ratio of three (3) may drain more quickly than a network with a ratio of two (2).

In block 910, an amount of data buffered in a network is determined. The amount of data buffered in the network may affect the time required to drain the buffered data. In some aspects, block 910 may be performed substantially in conformance with the description of block 605 discussed above with respect to FIG. 6A. In block 915, a network queue drain duration is determined based at least in part on the measurement and on the amount of data buffered. In some aspects, the network queue drain duration may be determined according to Equation (15) discussed above.

FIG. 9B is a functional block diagram of an exemplary device 950. In an embodiment, device 950 may be implemented as wireless device 202, illustrated in FIG. 2. The device 950 includes means 955 for determining, via an electronic device, a measurement of an amount of transmitted network data relative to an amount of received network data. In an embodiment, means 955 may be configured to perform one or more of the functions discussed above with respect to block 905. The means for determining a measurement 955 may include a processor, such as processor 204 of FIG. 2. Means 955 may also include one or more of a signal generator, transceiver, decoder, or a combination of hardware and/or software component(s), circuits, and/or module(s). The device 950 further includes means 960 for determining an amount of data buffered in a network. In an embodiment, means 960 may be configured to perform one or more of the functions discussed above with respect to block 910. The means 960 for determining an amount of data buffered in a network may include a processor, such as processor 204 of FIG. 2. Means 960 may also include one or more of a processor, signal generator, transceiver, decoder, or a combination of hardware and/or software component(s), circuits, and/or module(s). The device 950 further includes means 965 for determining the network queue drain duration based at least in part on the measurement and the amount of data buffered. In an embodiment, means 965 may be configured to perform one or more of the functions discussed above with respect to block 915. In an embodiment, the means for determining a network queue drain duration based at least in part on the measurement and the amount of data buffered may include a processor, such as processor 204 of FIG. 2. Means 965 may also include one or more of a signal generator, transceiver, decoder, or a combination of hardware and/or software component(s), circuits, and/or module(s).

FIG. 10A is a graph illustrating the relationship between a transmission and reception rate. The top line labeled "Tx" represents a transmission rate over time, while the lower line labeled "R" represents a receive rate over time. During a first time period before T_0 , the transmission rate exceeds the receive rate. This can be observed in that the slope of the transmission rate line at 1010 is greater than the slope of the receive line at 1020. This relationship between the slope of the two lines results in increasing distance between the two lines before time T_0 . This increasing distance represents data buffered in the network. At time T_0 , the transmission rate is reduced. This can be seen as a decreased slope of the top line Tx at 1030 when compared to the slope of the transmission line at 1010. During the time period between T_0 and T_1 , the receiver initially continues to receive at a high rate. Because the rate of transmission has decreased after T_0 , the receiver is able to reduce the amount of data buffered in the network during the time period between T_0 and T_1 . As the amount of data buffered in the network decreases, the rate of reception

may also be reduced, as can be observed by the inflection in the receive rate at 1040. In an embodiment, the time between T_0 , when the transmission rate is reduced, and T_1 , when the ratio of the reception rate to the transmission rate is approximately one (1), may be considered a network queue drain duration. After time T_1 , the transmission rate and reception rate are approximately equal, as can be seen by the relatively equivalent slopes of the transmission line Tx and reception line R after T_1 . The distance between the transmission rate and the reception rate may represent a nominal amount of data buffered in the network after a steady state transmission and reception rate is achieved.

FIG. 10B is a graph illustrating network delay. The time axis of FIG. 10B is spatially correlated with the time axis of FIG. 10A. During the portion of the graph of FIG. 10B before time T_0 , delay increases as the transmission rate exceeds the reception rate and data in the network is buffered as shown at 1060. At time T_0 , the transmission rate is reduced, as shown in the graph of FIG. 10A. As data buffered in the network drains and the amount of buffered data is reduced, delay is reduced, as shown at 1070. At time T_1 , when the amount of data buffered in the network is nominal as shown by FIG. 10A, nominal delays are also experienced, as shown in FIG. 10B at 1080.

FIG. 11A illustrates a process flow diagram for a method of determining a one way network transmission delay. In some network environments, dividing a network round trip time by two may not provide a reliable indication of a one way network transmission delay. For example, if one direction suffers disproportionately high delay, an inaccurate one way transmission delay may be determined with this approach. In embodiments that utilize a one way transmission delay to determine a transmission rate, dividing the round trip time by two may result in inappropriate changes to the transmission rate based on an inaccurate estimate of the one way transmission delay.

In an embodiment, process 1100 may be performed by the wireless device 202 illustrated in FIG. 2. In processing block 1105, a round trip network transmission time may be determined. In an embodiment, block 1105 may be performed substantially in accordance with process 800, illustrated in FIG. 8A. In block 1110, an indication of an elapsed duration of time between a reception of a first message and a reception of a second message is received. This elapsed duration of time may be known as an inter-arrival duration. In an embodiment, the indication may be transmitted by a receiver of the first and second message. In an embodiment, process 1100 may also include sending the first and second message to the receiver. In this embodiment, an elapsed duration of time between sending the first and second message may be known as an inter-transmittal duration.

In block 1115, a one way network transmission delay is determined based on the round trip network transmission time and the indication. In an embodiment, the one way network transmission delay may be determined based on the inter-arrival duration. In an embodiment, the one way network transmission delay may also be determined based on an inter-transmittal duration.

For example, the determined round trip time may be weighted by a ratio of the inter-arrival duration and inter-transmittal duration discussed above to determine a one way network transmission delay. In an embodiment, forward and reverse direction delays may be determined as:

$$D_r(t_n) = \Delta'_{RR}(t_n) \quad (16)$$

$$D_F(t_n) = \Delta'_{RR}(t_n) - D_r(t_n) \quad (17)$$

Where:

$D_r(t_n)$ is a reverse direction network one way transmission delay

$D_F(t_n)$ is a forward direction network one way transmission delay

$\Delta'_{RR}(t_n)$ is the determined round trip time

The forward direction one way time may be the network one way transmission time when transmitting data from the node performing process **1100** to a receiving node. The reverse direction one way time may be the network one way transmission time when the node performing process **1100** receives network data from the receiving node. In another embodiment, forward and reverse direction one way transmission times may be determined as below:

$$D_r(t_n) = \left(\frac{\text{inter-arrival duration } (m)}{\text{inter-transmittal duration } (m)} \right) \cdot \Delta'_{RR}(t_n) / 2, \quad (18)$$

$$\text{clip } [D_r(t_n), \{0, \Delta'_{RR}(t_n)\}]$$

$$D_F(t_n) = \Delta'_{RR}(t_n) - D_r(t_n) \quad (19)$$

FIG. **11B** is a functional block diagram of an exemplary device **1150**. In an embodiment, device **1150** may be implemented as wireless device **202**, illustrated in FIG. **2**. The device **1150** includes means **1155** for determining a round trip network transmission time. In an embodiment, means **1155** may be configured to perform one or more of the functions discussed above with respect to block **1105**. The means for determining a round trip network transmission time may include a processor, such as processor **204** of FIG. **2**. Means **1155** may also include one or more of a signal generator, transceiver, decoder, or a combination of hardware and/or software component(s), circuits, and/or module(s). The device **1150** further includes means **1160** for receiving an indication of an elapsed time between a reception of a first message and a reception of a second message. In an embodiment, means **1160** may be configured to perform one or more of the functions discussed above with respect to block **1110**. The means **1160** for receiving an indication of an elapsed duration of time between the reception of a first message and a second message may include a receiver, such as receiver **212** of FIG. **2**. Means **1160** may also include one or more of a processor, signal generator, transceiver, decoder, or a combination of hardware and/or software component(s), circuits, and/or module(s). The device **1150** further includes means **1165** for determining a one way network transmission delay based on the round trip network transmission time and the indication. In an embodiment, means **1165** may be configured to perform one or more of the functions discussed above with respect to block **1115**. In an embodiment, the means for determining a one way network transmission time based on the round trip network transmission delay and the indication may include a processor, such as processor **204** of FIG. **2**. Means **1165** may also include one or more of a signal generator, transceiver, decoder, or a combination of hardware and/or software component(s), circuits, and/or module(s).

FIG. **12** illustrates one embodiment of a transmitter report **1200**. The transmitter report **1200** includes data fields that may be utilized for achieving encoder adaptation. In an embodiment, these fields may be derived from a custom feedback structure, such as an RTP-extension. In an embodiment, the fields may be derived from a RTCP AVP and/or AVPF standard structures.

As discussed above, to dynamically adapt encoder parameters as described above based on conditions of a network

between a transmitter and a receiver, a feedback loop between the transmitter and the receiver may be established. Some embodiment may utilize receiver reports, such as receiver report **400** described above to communicate information on received data to the transmitter. In some other embodiments, a transmitter report, such as transmitter report **1200**, may be transmitted to a receiver. The receiver may then determine a target transmission or encoding rate. The receiver may then transmit this information to a transmitter or encoder. In some embodiments, transmitter reports and receiver reports may be utilized.

In an embodiment, transmitter reports may be transmitted to the receiver at a periodic interval, which may be configurable. In an embodiment, transmitter reports may be event-triggered. For example, transmitter reports may be transmitted when changes to one or more network conditions cross one or more predetermined thresholds. The size and structure of the transmitter report, such as the number of fields, size of the fields, or the type of the fields, may vary from that shown in FIG. **12**, and may also vary based on the network statistics being reported. In some embodiments, transmitter reports may piggy-back on other network communication packets between the transmitter and the receiver. For example, in an embodiment utilizing the Real Time Protocol (RTP), transmitter reports may be appended as a custom RTP extension payload format for video packets.

In some embodiments, transmitter reports may be structured and communicated using the RTCP AVP and/or AVPF standards. For example, in an embodiment utilizing RTCP AVPF feedback protocols, the above information may be derived from a combination of fields in the Regular/Immediate mode RTCP Sender/Receiver Reports, Generic NACK, Picture Loss Indication (PLI), TMMBR/TMMBN tuples and Full Intra Request (FIR) messages.

The fields of the transmitter report **1200** may refer to a context of the transmitter of the transmitter report. The transmitter report **1200** may include a far tag time received field **1205**. The far tag time received field **1205** may have been previously received by the transmitter of the transmitter report **1200**. The transmitter report **1200** also includes a duration held tag time **1210**. In an embodiment, the duration held tag time field **1210** indicates a duration of time between when the far tag time provided in field **1205** was received and the transmitter report was transmitted. The transmitter report **1200** also includes a near tag time sent field **1215**. In some embodiments, the near tag time sent field **1215** will be returned as the far tag time received field **1205**, contained in a transmitter report originating from a device receiving transmitter report **1200**. In some embodiments, the receiver of the transmitter report **1200** is expected to transmit the near tag time field **1215** back to the transmitter of the transmitter report. The transmitter report **1200** also includes a cumulative transmission count field **1220**. In one embodiment, the cumulative transmission count field **1220** indicates a cumulative number of transmitted messages transmitter by the transmitter of the report. The transmitter report **1200** also includes a cumulative loss count field **1225**. The cumulative loss count **1225** indicates a cumulative number of lost messages or packets detected by the transmitter generating the transmitter report **1200**. The transmitter report **1200** further includes a cumulative transmitted AU count field **1230**. The cumulative transmitted AU count field **1230** indicates the cumulative number of video access units transmitted by the transmitter of the transmitter report. The transmitter report **1200** further includes two cumulative bytes transmitted fields **1235** (high order bits) and **1240** (low order bits). The cumulative bytes transmitted fields **435** and **440** indicate a total number of bytes

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transmitted within a network communication channel by the transmitter transmitting the transmitter report **1200**. The transmitter report **1200** also includes an AU metadata field **1245**. The AU metadata field indicates frame information. In an embodiment, transmitter reports may vary in size depending on whether they only carry delay related information, known as short transmitter reports, or if they also include network throughput and loss statistics, known as full transmitter reports.

As shown, the transmitter report contains aggregate byte counts and transmitter time-line information. Information contained in a transmitter report may be used to determine a moving average transmission rate, $R'_v(t)$, which is used as an indicator of throughput. In an embodiment, $R'_v(t)$ may represent a rate in kilobits per second. In one embodiment, $R'_v(t)$ may be derived as a rectangular moving average as:

$$R'_v(t) = \frac{\left(\int_{t-\Delta t}^t b(t) \right)}{\Delta t} \Big|_{\Delta t \geq \Delta t_f; R_f = K \text{ (Constant)}} \quad (20)$$

where:

$b(t)$ is the bytes transmitted at time t on a transmitter clock
 Δt is an interval for calculating an average

Δt_f is a minimum interval for a reliable average, and

R_f is the current receiving rate

The interval Δt_f should be determined to ensure a reliable average that is robust to network jitter. To provide for an ability to adapt to a drop in network throughput within an acceptable timeframe, transmitter reports providing byte counts and timing information used in calculating a throughput may be provided at a finer resolution than Δt_f , denoted as Δt_{tr} , where $\Delta t_{tr} \ll \Delta t_f$. In an embodiment, a receiver may store previously received transmitter reports. The receiver may search the stored transmitter reports for a most recent report such that $\Delta t_{tr} \geq \Delta t_f$ at a static encoding rate R'_v .

The throughput estimate may be improved by use of an averaging strategy to smooth network jitter. In an embodiment, a single-tap (LP) infinite impulse response (IIR) filter may be employed as:

$$R'_v(t_n) = \beta \cdot R'_v(t_n - 1) + (1 - \beta) \cdot R'_v(t_n) \quad (21)$$

where:

$R'_v(t_k)$ is the one-tap IIR average throughput estimate at time t_k ($k=n, n-1$)

$R'_v(t_n)$ is the rectangular moving average throughput calculation for the current instant t_n

The calculated transmission throughput above includes a delay $D_r(t_n)$ which may be composed of delays introduced when a transmitter report is transmitted, and then received and parsed by the receiver. Because of this delay, $R'_v(t_n)$ refers to a throughput estimate at the transmitter as observed at time $(t_n - D_r(t_n))$ on the receiver's clock. To use the calculated throughput, a consumption to production ratio is determined. This ratio will generally not fall below a threshold for a given number of tokens. This ratio is discussed above with respect to FIG. 5A when determined in one aspect by a transmitter and FIG. 13A when determined in one aspect by a receiver.

FIG. 13A illustrates a process flow diagram for a method of encoding multimedia information. In an embodiment, process **1300** may be performed by the wireless device **202** illustrated in FIG. 2. In an embodiment, process **1300** may be performed by the device **202** of FIG. 2. In another embodiment, process **1300** may be performed by a receiver. In processing block **1305**, a measurement of an amount of received network data relative to an amount of transmitted network

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data is determined. In some aspects, the measurement may be a ratio of received network data to transmitted network data. In an embodiment, the ratio may be calculated as:

$$\rho(t_n) = R_f(t_n) / R'_v(t_n) \quad (22)$$

where:

t_n is a time n at a receiving node

$R'_v(t_n)$ is an estimated encoding rate at time n

$R_f(t_n)$ is a receiving rate at time n

In an embodiment, a receiver may maintain a record of a receiving rate over time. For example, an embodiment may define a duration of time during which an amount of data received is accumulated and recorded. When the duration of time has expired, a second time period may begin, with the amount of data received during the second time period accumulated and recorded. This process repeats, resulting in a series of recorded receiving rates, representing an amount of data received over each successive time period. A receiver may obtain the amount of data encoded or transmitted during one or more periods via a transmitter report, such as transmitter report **1200** discussed above with respect to FIG. 12. In an embodiment, transmitter reports may be received periodically. In an embodiment, the transmission of transmitter reports may be event-triggered. In an embodiment, both event-triggered and periodic transmitter reports may be received by a receiver. In an embodiment, the frequency with which transmitter reports are received may be correlated with the frequency with which the receiving rates are accumulated and stored as discussed above. In another embodiment, the frequency of transmitter reports may be uncorrelated with the frequency at which receiving information is accumulated by a receiver.

In an embodiment, the receiving rate, such as $R_f(t_n)$, may be determined by a receiver based on data actually received by the receiver.

In an embodiment, the ratio of received network data to transmitted network data may be based on a receiving rate and a transmission rate correlated in time as discussed above. For example, the rates used to determine the ratio may be delay adjusted moving average rates. In some embodiments, the transmitting rates and receiving rates may be correlated by adjusting the transmitting rate information based on a delay. For example, transmitting information may be transmitted by a transmitter in a transmitter report to a receiver. The transmitter report may be received by the receiver after a delay period caused by at least network delays and delays associated with the transmitter assembling and packaging the transmitting information for transmission to the receiver. Because the transmitter and receiver may not share a common clock, it may not be possible to correlate transmitting information and receiving information based on a timestamp or other absolute timing information. Instead, an estimate of the delay from when transmitting information is collected to when the transmitting information is received by the receiver may be used to correlate the transmitting information with local receiving information. In an embodiment, the delay may be determined in a manner substantially in accordance with process **1100**, illustrated in FIG. 11. By correlating an encoding or transmitting rate and a receiving rate for a single time period, the ratio more accurately reflects the relationship between consumption and production during the single time period.

The ratio, in an embodiment $\rho(t_n)$, may provide an indication of network conditions between a transmitter and a receiver. For example, if the ratio is approximately one (1), this may indicate that a rate of transmission at a time t_n , minus a delay $D_r(t_n)$ was sustainable. In some embodiments, a ratio within a distance ϵ from one (1) may also be considered to

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indicate sustainable network conditions. A ratio of approximately one (1) or one $(1) \pm \alpha$ does not necessarily indicate 100% channel utilization.

If the ratio is less than one, or less than $(1 - \alpha)$ as described above, it may indicate a current encoding or transmission rate, for example, $R'_v(t_n)$ in an embodiment utilizing equation (1), is not sustainable. To verify a low ratio indicates a transmission rate is not sustainable, a receiver may maintain a record of receiver delay-adjusted moving average output rates, for example, $\{r'_v(t_n), r'_v(t_{n-1}), r'_v(t_{n-2}), \dots\}$. The ratio may then be calculated as:

$$\rho(t_n) = R_f(t_n) / r'_v(t_n) \quad (23)$$

where:

t_n is a receiver instant in time when transmitter report 'n' is received

$R_f(t_n)$ is a receiving rate at time t_n

$r'_v(t_n)$ is estimated over the interval $[t_{n-1} - D_T(t_{n-1}), t_n - D_T(t_n)]$, and

$D_T(t_n)$ is an average reverse direction delay for transmitter report arrival at time t_n

If the ratio is greater than one, or greater than one $(1) + \alpha$ as described above, it may indicate that buffered data in the network is being received at a rate higher than new data is being encoded and sent over the network. A ratio greater than one may be experienced after a network recovers from a period of reduced throughput. During the period of reduced throughput, transmission of data by a data source into the network based on an encoding rate may exceed a capacity of the network to transfer data to the receiver. Some of this excess data may be buffered, and some of the excess data may be dropped. When the network recovers and throughput of the network increases, the buffered data in the network may be sent to the receiver. This data may be received by the receiver at a rate that exceeds the transmission rate.

At block 1310, an encoding parameter is transmitted based on the determined measurement. In an embodiment, the encoding parameter is transmitted to a transmitting node. In an embodiment, the encoding parameter transmitted may be a recommended encoded parameter for the transmitting node to use when encoding or transmitting data.

Encoding parameters transmitted based on the measurement may include bit rate parameters, temporal adaptation parameters, spatial adaptation parameters, or error resiliency parameters, as discussed previously. The transmitted encoding parameters may be different than one or more current encoding parameters used by the transmitting node.

In an embodiment, if the determined measurement is a ratio, and the ratio is less than one, or $(1 \pm \alpha)$ as described above, the one or more transmitted encoding parameters may function to reduce the size of encoded multimedia data generated by an encoder at the transmitting node. In an embodiment, encoding parameters may be adjusted to render encoded data more resilient to errors if the determined ratio is less than one, or less than $(1 \pm \alpha)$. For example, the encoding bit rate may be reduced if the determined ratio is less than one, or $(1 \pm \alpha)$ as described above. In an embodiment, a recommendation to increase the encoding bit rate may be transmitted to the transmitting node if a predetermined number of sequential ratios are more than one, or $(1 \pm \alpha)$ as described above.

In an embodiment, a recommended encoding parameter may not be transmitted until a sequential threshold number F_p of ratios are determined to be less than one (1) or $(1 - \alpha)$. For example, if a ratio is determined for each sequential token or quanta, a predetermined number F_p of sequential tokens having a ratio less than $(1 - \alpha)$ may be necessary before a recom-

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mended encoding parameter is transmitted. This may avoid over reacting to spurious deviations in network state.

In an embodiment, an encoding parameter may be transmitted when fewer than F_p sequential ratios are determined to be less than $(1 - \alpha)$ and a forward link delay is above a second threshold, for example, denoted as $D_F(t_n) \geq D_F^U$.

In an embodiment, the receiver side throughput influence on a transmission rate may be expressed with the following Boolean functional:

$$B(R_v(t_n+1) < (R_v(t_n))) = \{ \rho(t_n) < (1 - \alpha) \& f_p \geq F_p \} \cup \{ \rho(t_n) < (1 - \alpha) \& D_F(t_n) \geq D_F^U \} \quad (24)$$

where:

t_n is a receiver time instant when a transmitter report 'n' is received

$R'_v(t_n)$ is an encoding rate estimate at time instant t_n

$\rho(t_n)$ is the ratio of received network data to transmitted network data (eq (23))

f_p is a number of sequential determined ratios indicating low throughput

F_p is a threshold number of sequential determined ratios indicating low-throughput

$D_F(t_n)$ is a forward-path delay estimate at receiver time instant t_n , and

D_F^U is a forward-path high delay threshold

Note that while in the embodiment discussed above, a receiver may recommend or suggest to a transmitter some transmission or encoding parameter adjustments when the ratio is less than one or less than $(1 - \alpha)$, it should be understood that other embodiments may determine a ratio that is the inverse of the ratio disclosed in the embodiment above. In these other embodiments, recommended or suggested transmission or encoding parameters may be transmitted in an opposite manner as those described above. For example, in these embodiments, if the determined ratio is more than one, or $(1 \pm \alpha)$, one or more encoding parameters may be recommended or suggested to a transmitter. These recommendations may reduce the size of encoded multimedia data generated by an encoder on the transmitting node. In an embodiment, encoding parameters may be transmitted by the receiver to the transmitter which suggest or recommend to render encoded data more resilient to errors if the determined ratio is more than one, or more than $(1 + \alpha)$. For example, the encoding bit rate may be reduced if the determined ratio is more than one, or $(1 + \alpha)$ as described above. In an embodiment, a receiver may recommend to the transmitter an encoding bit rate be increased if a predetermined number of sequential ratios are less than one, or $(1 - \alpha)$.

FIG. 13B is a functional block diagram of an exemplary device 1350. In an embodiment, device 1350 may be implemented as wireless device 202, illustrated in FIG. 2. The device 1350 includes means 1360 for determining, via an electronic device, a measurement of an amount of received network data relative to an amount of transmitted network data. In an embodiment, means 1360 may be configured to perform one or more of the functions discussed above with respect to block 1305. The means for determining a measurement 1360 may include a processor, such as processor 204 of FIG. 2. Means 1360 may also include one or more of a signal generator, transceiver, decoder, or a combination of hardware and/or software component(s), circuits, and/or module(s). The device 1350 further includes means 1365 for transmitting an encoding parameter based on the determined measurement. In an embodiment, means 1365 may be configured to perform one or more of the functions discussed above with respect to block 1310. The means 1365 for transmitting an encoding parameter based on the determined measurement

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may include a transmitter, such as transmitter **210** of FIG. **2**. Means **1365** may also include one or more of a processor, signal generator, transceiver, decoder, or a combination of hardware and/or software component(s), circuits, and/or module(s).

FIG. **13C** is a timing diagram illustrating the correlation of transmitting information with receiving information at a receiver. FIG. **13C** shows a transmitter **1370**, receiver **1380**, and a correlator **1375**. In an embodiment, any of the transmitter **1370**, correlator **1375**, or receiver **1380** may be implemented by the wireless device **202**, illustrated in FIG. **2**. In some aspects, the correlator **1375** may be performed or executed on the same physical device as the receiver **1380**. As shown in FIG. **13C**, the receiver **1380** generates receiving information **1385a-d** periodically. FIG. **13C** shows receiving information **1385a-d** generated at times $T_{0..3}$, respectively. Transmitter **1370** is shown transmitting transmitter reports **1387a-d** to correlator **1375**. These transmitter reports are generated by the transmitter **1380** at times $T_{0..3}$ respectively. Because of at least network delays, transmitter reports **1387a-d** are received by the correlator **1375** at times $T_{0'..3'}$, respectively. Based on a determination of a network delay, correlator **1375** may correlate the receiving information **1385a-d** with transmitting information **1386a-d**. This is shown in FIG. **13C** as the dashed arrows associating transmitting information **1386a-d** with receiving information **1385a-d**. In an embodiment, correlator **1375** and receiver **1380** may be implemented in the same wireless device.

Note that some implementations include transmitting nodes that send transmitter reports to a receiving node, while the receiving node transmits receiver reports to the transmitting node. In these implementations, aspects of FIGS. **5C** and **13C** may be combined. For example, the transmitting node may receive receiver reports and correlate information in the receiver report with transmitting information referenced to a transmitting node time reference. The receiving node may receive transmitter reports and correlate information in the transmitter report with receiving information referenced to a receiving node time reference. In these aspects, the receiving node may determine one or more encoding or transmission parameters and transmit the parameters to the transmitting node. The transmitting node may then adapt one or more encoding parameters based on the transmitted parameters.

FIG. **14A** illustrates a process flow diagram for a method of transmitting a parameter to a transmitting node. In an embodiment, process **1400** may be performed by a receiving node. In an embodiment, the transmitted parameter may represent a recommendation, suggestion or directive for a node receiving the parameter to adjust an encoding process based on the parameter. In an embodiment, process **1400** may be performed by the wireless device **202** illustrated in FIG. **2**. In processing block **1405**, an amount of data buffered in a network is determined.

In an embodiment, the amount of data buffered may be determined based at least in part on a period of time during which an amount of data transmitted via the network exceeded the network's capacity during the period. In an embodiment, this period of time may be determined as:

$$T_R \approx F_p \cdot \Delta t_{TR} \quad (25)$$

where:

T_R is a reaction time

F_p is a token threshold for throughput based rate reduction, and

Δt_{TR} is a transmitter report interval

In an embodiment, the amount of data buffered in the network may be based at least in part on how much the

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amount of data transmitted exceeds the network's capacity during the time period. In an embodiment, if a transmission rate is $R'_v(t_n)$, the amount the transmission rate exceeds the network's capacity at an instant in time t_n may be expressed as:

$$R_{surplus} = R'_v(t_n) - R_f(t_n) \quad (26)$$

where:

$R'_v(t_n)$ is an estimated transmitter throughput at time instant t_n

$R_f(t_n)$ is a receiver throughput at time instant t_n

In an embodiment, the amount of data buffered in a network may then be:

$$b_R = R_{surplus} \cdot T_R \text{ or} \quad (27)$$

$$b_R = (R'_v(t_n) - R_f(t_n)) \cdot F_p \cdot \Delta t_{TR} \quad (28)$$

In some other aspects, block **1405** may be performed in substantial accordance with the description of block **605**, discussed above with respect to FIG. **6A**. In processing block **1410**, a sustainable throughput of the network is determined. In an embodiment, the sustainable throughput may be based, at least in part, on a margin of safety. The margin of safety may be determined so as to provide an opportunity for data buffered during a period of reduced network capacity (for example, due to network congestion or hardware failure) to complete transmission after the network's capacity improves. In some embodiments, the margin of safety may be based, at least in part, on a percentage of a determined network capacity. For example, in an embodiment, ten percent of a determined network capacity may be reserved to provide an excess capacity. In some aspects, block **1410** may be performed in substantial accordance with the description of block **610**, discussed above with respect to FIG. **6A**.

In block **1415**, a recommended or suggested transmission rate is determined based on the sustainable throughput and the amount of data buffered. In an embodiment, the suggested or recommended transmission rate should be determined such that the amount of data buffered in a network is eliminated or drained within a time period t_R . In some environments, a value of one second for time period t_R provides good results. In an embodiment, the transmission rate may be determined as:

$$r'_v(t_{n+1}) = R_f(t_n) (1 - R_H^{\%}) - b_R \quad (29)$$

where:

$R_H^{\%}$ represents a percentage of network capacity based on the margin of safety discussed above, and

b_R represents the amount of data buffered in the network as discussed above with respect to Equation 14 t_R is assumed to be unity (1 second)

In an embodiment, a final rate $R'_v(t_{n+1})$ may be obtained by quantizing $r'_v(t_{n+1})$ to a value from an operational range of rates $R_v(D)$ as:

$$R'_v(t_{n+1}) = \text{Quant}(R_v(D)[r'_v(t_{n+1})]), \text{ where } R_v \leq r'_v \quad (30)$$

In block **1420**, a parameter is transmitted. The parameter is based at least on at least one of the amount of data buffered in the network and the sustainable throughput. In some aspects, the transmission rate is transmitted. Other parameters transmitted may include bit rate parameters, temporal adaptation parameters, spatial adaptation parameters, or error resiliency parameters, as discussed previously with respect to block **1310**. Some implementations of process **1400** do not include block **1415**.

FIG. **14B** is a functional block diagram of an exemplary device **1450**. In an embodiment, device **1450** may be implemented as wireless device **202**, illustrated in FIG. **2**. The

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device **1450** includes means **1455** for determining an amount of data buffered in a network. In an embodiment, means **1455** may be configured to perform one or more of the functions discussed above with respect to block **1405**. The means for determining an amount of data buffered may include a processor, such as processor **204** of FIG. **2**. Means **1455** may also include one or more of a signal generator, transceiver, decoder, or a combination of hardware and/or software component(s), circuits, and/or module(s). The device **1450** further includes means **1460** for determining a sustainable throughput of the network. In an embodiment, means **1460** may be configured to perform one or more of the functions discussed above with respect to block **1410**. The means **1460** for determining an amount of data buffered in a network may include a processor, such as processor **204** of FIG. **2**. Means **1460** may also include one or more of a processor, signal generator, transceiver, decoder, or a combination of hardware and/or software component(s), circuits, and/or module(s). The device **1450** further includes means **1465** for determining a transmission rate based on the sustainable throughput and the amount of data buffered. In an embodiment, means **1465** may be configured to perform one or more of the functions discussed above with respect to block **1415**. The means **1465** for determining an amount of data buffered in a network may include a processor, such as processor **204** of FIG. **2**. Means **1465** may also include one or more of a processor, signal generator, transceiver, decoder, or a combination of hardware and/or software component(s), circuits, and/or module(s). Some implementations of device **1450** do not include means **1465**. The device **1450** further includes means **1470** for transmitting a parameter based on at least one of the amount of data buffered in the network and the sustainable throughput of the network. In an embodiment, means **1470** may be configured to perform one or more of the functions discussed above with respect to block **1420**. The means **1470** for transmitting a parameter based on at least one of the amount of data buffered in the network and the sustainable throughput of the network may include a transmitter, such as transmitter **210** of FIG. **2**. Means **1470** may also include one or more of a processor, signal generator, transceiver, decoder, or a combination of hardware and/or software component(s), circuits, and/or module(s).

FIG. **15A** illustrates a process flow diagram for a method of determining an encoding parameter. In an embodiment, process **1500** may be performed by the wireless device **202** illustrated in FIG. **2**. In some aspects, process **1500** may be performed by a transmitting node encoding and transmitting information on a network. The transmitting node may determine an encoding rate at which it transmits data to the receiving node. For example, the node may perform process **500** and/or process **600** as described above with respect to FIGS. **5A** and **6A**. Process **1500** may be performed in some aspects as part of block **510** of process **500**, and/or block **620** of process **600**, and/or block **1310** of process **1300**, and/or block **1420** of process **1400**. In some aspects, the determined encoding rate may be based on receiver reports, such as receiver report **400**, received from a receiving node that receives the transmitted data.

In some aspects, the transmitting node may transmit transmitter reports, such as transmitter report **1200** described above with respect to FIG. **12**, to the receiving node. The transmitting node may also receive a suggested or recommended encoding or transmitting parameter from the receiving node.

In some implementations only one of the receiving or transmitting nodes may determine one or more encoding parameters. In these embodiments, data transmitted by the

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transmitting node may be based on the encoding parameters determined by the one node. In some other implementations, both the transmitting node and the receiving node may determine encoding parameters. In these implementations, the transmitting node may reconcile the two sets of encoding parameters (determined by the transmitting node and receiving node) to determine a “final” set of encoding parameter(s). This “final” encoding parameter set may be used to encode data before transmission to the receiving node. Process **1500** illustrates one possible implementation of a process to reconcile encoding parameters. The example process **1500** determines “final” or “hybrid” encoding parameters under three scenarios. Those scenarios include 1) only parameters determined by the transmitting node are available; 2) only parameters determined by the receiving node are available; or 3) both parameters determined by the transmitting node and parameters determined by the receiving node are available.

Block **1505** determines whether receiver determined encoding parameters are available. In some implementations, a receiver may not determine encoding parameters. In some implementations, a transmitting node may not transmit a transmitter report, such as transmitter report **1200** to the receiver. In these implementations, the receiver may not have the information available to determine one or more transmission or encoding parameters. In these implementations, process **1500** moves from decision block **1505** to block **1510**, which determines whether transmitter determined encoding parameters are available. If transmitter determined encoding parameters are not available, hybrid encoding parameters are determined in block **1545** based on default values, since neither receiver determined nor transmitter determined encoding parameters are available. If transmitter determined encoding parameters are available, process **1500** moves to block **1515**, where hybrid encoding parameters are determined based on the transmitter determined encoding parameters.

In some other implementations, the receiver may determine one or more encoding parameters. For example, in some of these implementations, a transmitter report such as transmitter report **1200** may be sent to the receiver. The receiver may then perform process **1300** and/or process **1400** and transmit one or more encoding or transmission parameters to the transmitting node. In these implementations, process **1500** moves from decision block **1505** to decision block **1520**, which determines whether transmitter determined encoding parameters are available. Some implementations may rely entirely on a receiver to determine one or more encoding parameters. In these implementations, determinations by the receiver may be more accurate than determinations by a transmitting node. In these implementations, process **1500** moves from block **1520** to block **1525**, where hybrid encoding or transmission parameter(s) are determined based on receiver determined encoding parameter(s).

If both transmitter determined and receiver determined encoding parameter(s) are available, process **1500** moves from decision block **1520** to block **1530**, where a confidence score is determined for the receiver determined encoding parameter(s). The confidence score may be based on one or more of a history of encoding parameter recommendations or suggestions by the receiver, the timing of encoding parameter recommendations or suggestions by the receiver, signaling availability of the receiver, and/or a history of encoder rate adaptation (for example, if the encoder has recently increased an encoding or transmitting rate, decreased the encoding or transmitting rate, or maintained the encoding or transmitting rate).

In block **1535** a confidence score is determined for the transmitter determined one or more encoding parameters.

The confidence score may be based on one or more of a history of encoding parameter recommendations or suggestions by the transmitter, the timing of encoding parameter recommendations or suggestions by the transmitter, signaling availability of the transmitter, and/or a history of encoder rate adaptation (for example, if the encoder has recently increased an encoding or transmitting rate, decreased the encoding or transmitting rate, or maintained the encoding or transmitting rate).

In block **1540**, hybrid encoding parameters are determined based on the confidence scores, the transmitter determined encoding parameter(s), and the receiver determined encoding parameter(s).

In some other embodiments, blocks **1530-1540** may not be performed. Instead, hybrid encoding parameters may be determined to achieve a minimum change resulting in a current encoding rate if either the transmitter encoding parameter(s) or the receiver determined encoding parameter(s) are utilized. In still other embodiments, block **1530-1540** may not be performed. Instead, hybrid encoding parameters may be determined based on a minimum transmission or encoding rate resulting from application of either the transmitter determined encoding parameter(s) or the receiver determined encoding parameter(s).

FIG. **15B** shows a functional block diagram for a wireless communication apparatus. Those skilled in the art will appreciate that a wireless communication apparatus may have more components than the simplified wireless communication apparatus **202** shown in FIG. **2**. The wireless communication apparatus **1550** shown includes only those components useful for describing some prominent features of implementations within the scope of the claims. In some aspects, apparatus **1550** may include one or more of the components or circuits of apparatus **550**, **650**, **850**, **950**, **1150**, **1350**, **1450**, or **1650**. The wireless communication apparatus **1550** may include a receiver determined encoding parameter(s) circuit **1560**, a confidence score determination circuit **1565**, a transmitter determined encoding parameters circuit **1570**, and a hybrid encoding parameters determination circuit **1575**.

In some implementations, the receiver determined encoding parameters circuit **1560** may be configured to perform one or more of the functions discussed above with respect to blocks **1505**. The receiver determined encoding parameters circuit **1560** may include one or more of a programmable chip, a processor, a memory, and a network interface. For example, the receiver determined encoding parameters circuit **1560** may include the processor **204**. In some implementations, a means for determining receiver determined encoding parameters may include the receiver determined encoding parameters circuit **1560**.

In some implementations, the confidence score determination circuit **1575** may be configured to perform one or more of the functions discussed above with respect to blocks **1530**, and/or **1540**. The confidence score determination circuit **1565** may include one or more of a programmable chip, a processor, a memory, and a network interface. For example, the confidence score determination circuit **1565** may include the processor **204**. In some implementations, a means for determining a confidence score may include the confidence score determination circuit **1565**.

In some implementations, the transmitter determined encoding parameters circuit **1570** may be configured to perform one or more of the functions discussed above with respect to blocks **1510**, and/or **1520**. The transmitter determined encoding parameters circuit **1570** may include one or more of a programmable chip, a processor, a memory, and a network interface. For example, the transmitter determined

encoding parameters circuit **1570** may include the processor **204**. In some implementations, a means for determining transmitter determined encoding parameters may include the transmitter determined encoding parameters circuit **1570**.

In some implementations, the hybrid encoding parameters determination circuit **1575** may be configured to perform one or more of the functions discussed above with respect to blocks **1515**, **1525**, and/or **1540**. The trans hybrid encoding parameters determination circuit **1575** may include one or more of a programmable chip, a processor, a memory, and a network interface. For example, the hybrid encoding parameters determination circuit **1575** may include the processor **204**. In some implementations, a means for determining hybrid encoding parameters may include the hybrid encoding parameters circuit **1575**.

FIG. **16A** illustrates a process flow diagram for a method of determining an encoding parameter. In some aspects, process **1600** utilizes jitter information as auxiliary information for the purpose of dynamic bitrate adaptation. Jitter information may be utilized to accelerate an encoding or transmission rate increase or decrease when certain conditions are met.

In an embodiment, process **1600** may be performed by the wireless device **202** illustrated in FIG. **2**. In some aspects, process **1600** may be performed by a node or device encoding and transmitting information on a network. The encoding or transmitting node may determine an encoding rate. For example, the encoding or transmitting node may perform process **500** and/or process **600** as described above with respect to FIGS. **5A** and **6A**. In some aspects, process **1600** may be performed by a receiving node determining an encoding parameter for a transmitting or encoding node. The receiving node may perform one or more of processes **1300**, and/or **1400**. Therefore, in various aspects, process **1600** may be performed as part of one or more of blocks **510**, **615**, **620**, **1310**, and/or **1415**.

Some implementations define at least two jitter thresholds:

J_{th}^{dec} : Jitter threshold for rate decrease

J_{th}^{inc} : Jitter threshold for rate increase

The above jitter thresholds may be determined based on moving averages of inter-arrival jitter of each packet after a classification defined as below.

include current inter-arrival jitter value in a moving window to compute J_{th}^{dec} if

$$B < (1 - \alpha)R \text{ or } D_0 > D_{th}^{dec}$$

And compute J_{th}^{dec} by moving average filtering.

Otherwise, include current inter-arrival jitter value in a moving window to compute J_{th}^{inc} if

$$B > (1 - \beta)R \text{ and } D_0 < D_{th}^{inc} \text{ or } B < (1 - \beta)R \text{ and } D_0 < D_{th}^{inc}$$

And compute J_{th}^{inc} by moving average filtering.

Where

B: throughput measured or estimate

R: encoding rate

D_0 : amount of data buffered in a network

P_{th}^{inc} : threshold of amount of data buffered in a network to consider rate increase

D_{th}^{dec} : threshold of amount of data buffered in a network to consider rate decrease

α, β : design parameters

Since filtering of jitter data may be improved with a certain amount of data available, initial data may be used to train the jitter thresholds in some implementations. In these implementations, use of jitter thresholds to further adjust encoding parameter(s) may not be performed when the moving average jitter values are being trained. When the moving average jitter values become available after a training period, the measured

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network jitter may be utilized to either reduce or increase rate further. For example, network jitter may be used in some implementations when:

1. throughput or bandwidth, and or loss, and or delay indicates encoding or transmission rate should be reduced, determine if the current inter-arrival jitter J meets the following condition:

$$J > (1 - \gamma)_{th}^{dec}$$

if this condition is met, then encoding or transmission rate is further reduced by Δ^{dec} .

2. throughput or bandwidth, and or loss, and or delay indicates encoding or transmission rate should be increased, determine if the current inter-arrival jitter J meets the following condition:

$$J < (1 + \delta)_{th}^{inc}, \text{ and } D_0 < D_{th}^{inc}, \text{ and } B \approx R$$

if this condition is met, then encoding rate is further increased by Δ^{inc} .

One example implementation of the above described method is illustrated as process **1600** and shown in FIG. **16A**. In some aspects, process **1600** is performed by the wireless device **202**, shown in FIG. **2**. Process **1600** may be performed in some aspects as part of block **510** of process **500**, and/or block **620** of process **600**, and/or block **1310** of process **1300**, and/or block **1420** of process **1400**.

In block **1605**, a first adjustment is determined to an encoding parameter. In some aspects, determining an encoding parameter that is different than an existing encoding parameter may represent an adjustment to an encoding parameter. In block **1610**, a network jitter is determined. The network jitter may be packet inter-arrival jitter in some implementations. In some other aspects, the network jitter may be filtered network jitter information.

Block **1615** determines whether the first adjustment will increase a transmission rate. For example, in some aspects, one or more of processes **500**, **600**, **1300**, or **1400** may determine an encoding parameter that if applied, will result in an increase in the transmission rate of an encoding node utilizing the determined encoding parameter. In this case, process **1600** moves from decision block **1615** to decision block **1620**. In block **1620**, the network jitter is compared to a first jitter threshold. If the network jitter is less than the first jitter threshold, process **1600** moves to block **1630**, where a second adjustment to an encoding parameter is determined which further increases the transmission rate. In some aspects, an encoding parameter adjusted in block **1625** is also adjusted in block **1605**. For example, in some aspects, an encoding bit rate is increased in block **1605** and also increased further in block **1625**. In some other aspects, an error resiliency parameter may be adjusted in block **1605** and a temporal adaptation parameter and/or spatial adaptation parameter may be adjusted in block **1625**. In various aspects, one or more encoding parameters adjusted in block **1625** overlap or do not overlap with one or more encoding parameters adjusted in block **1605**.

If the first adjustment does not increase the transmission rate, block **1630** determines whether the first adjustment decreases the transmission rate. If the first adjustment does decrease the transmission rate, the network jitter is compared to a second jitter threshold in block **1635**. In the network jitter is greater than a second jitter threshold, then a second adjustment to an encoding parameter is determined to further decrease the transmission rate. If the network jitter is less than the second jitter threshold, process **1600** moves from block **1635** to block **1645**. In some aspects, the second jitter threshold is higher than the first jitter threshold.

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In block **1645**, the one or more adjusted encoding parameters are applied. If process **1600** is performed on an encoding or transmitting node, applying the adjusted encoding parameters may include encoding and/or transmitting data based on the adjusted encoding parameter(s). If process **1600** is performed on a receiving node, applying the adjusted encoding parameter(s) may include transmitting an indication of the adjusted encoding parameters to an encoding or transmitting node.

FIG. **16B** shows a functional block diagram for a wireless communication apparatus. Those skilled in the art will appreciate that a wireless communication apparatus may have more components than the simplified wireless communication apparatus **202** shown in FIG. **2**. The wireless communication apparatus **1650** shown includes only those components useful for describing some prominent features of implementations within the scope of the claims. In some aspects, apparatus **1650** may include one or more of the components or circuits of apparatus **550**, **650**, **850**, **950**, **1150**, **1350**, **1450**, or **1550**. The wireless communication apparatus **1650** may include a primary encoding adjustment circuit **1655**, a jitter determination circuit **1660**, a secondary encoding adjustment circuit **1665**, and a jitter thresholding circuit **1670**.

In some implementations, the primary encoding adjustment circuit **1655** may be configured to perform one or more of the functions discussed above with respect to block **1605**. The primary encoding adjustment circuit **1655** may include one or more of a programmable chip, a processor, a memory, and a network interface. For example, the primary encoding adjustment circuit **1655** may include the processor **204**. In some implementations, a means for determining a first adjustment to an encoding parameter may include the primary encoding adjustment circuit **1655**.

In some implementations, the jitter determination circuit **1660** may be configured to perform one or more of the functions discussed above with respect to block **1610**. The jitter determination circuit **1660** may include one or more of a programmable chip, a processor, a memory, and a network interface. For example, the jitter determination circuit **1660** may include the processor **204**. In some implementations, a means for determining a network jitter may include the jitter determination circuit **1660**.

In some implementations, the secondary encoding adjustment circuit **1665** may be configured to perform one or more of the functions discussed above with respect to block **1625** and/or **1640**. The secondary encoding adjustment circuit **1665** may include one or more of a programmable chip, a processor, a memory, and a network interface. For example, the secondary encoding adjustment circuit **1665** may include the processor **204**. In some implementations, a means for applying a second adjustment to an encoding parameter may include the secondary encoding adjustment circuit **1665**.

In some implementations, the jitter thresholding circuit **1670** may be configured to perform one or more of the functions discussed above with respect to block **1670**. The jitter thresholding circuit **1670** may include one or more of a programmable chip, a processor, a memory, and a network interface. For example, the jitter thresholding circuit **1670** may include the processor **204**. In some implementations, a means for determining whether a network jitter is above or below a threshold may include the jitter thresholding circuit **1670**. Throughout this disclosure, network nodes may be referred to as a transmitter, receiver, transmitting node, or receiving node. While most network nodes both transmit and receive data, use of these terms within this disclosure is intended to refer to a nodes respective role in the exchange of a unidirectional data stream whose transmission rate or encoding rate is

being managed by the methods described here. For example, a transmitter or transmitting node is a node transmitting the unidirectional data stream whose rate is being managed by the disclosed methods. A receiver or transmitting node is a node receiving a unidirectional data stream whose rate is being managed by the disclosed methods. The words “transmitter” and “receiver” may also be used to refer to hardware components, such as transmitter **210** and receiver **212**. However, one skilled in the art may easily differentiate between a transmitting node and a transmitter **210**, for example, based on the context in which the word is used.

As used herein, the terms “determine” or “determining” encompass a wide variety of actions. For example, “determining” may include calculating, computing, processing, deriving, investigating, looking up (e.g., looking up in a table, a database or another data structure), ascertaining and the like. Also, “determining” may include receiving (e.g., receiving information), accessing (e.g., accessing data in a memory) and the like. Also, “determining” may include resolving, selecting, choosing, establishing and the like.

As used herein, the terms “provide” or “providing” encompass a wide variety of actions. For example, “providing” may include storing a value in a location for subsequent retrieval, transmitting a value directly to the recipient, transmitting or storing a reference to a value, and the like. “Providing” may also include encoding, decoding, encrypting, decrypting, validating, verifying, and the like.

As used herein, a phrase referring to “at least one of” a list of items refers to any combination of those items, including single members. As an example, “at least one of: a, b, or c” is intended to cover: a, b, c, a-b, a-c, b-c, and a-b-c.

The various operations of methods described above may be performed by any suitable means capable of performing the operations, such as various hardware and/or software component(s), circuits, and/or module(s). Generally, any operations illustrated in the Figures may be performed by corresponding functional means capable of performing the operations.

The various illustrative logical blocks, modules and circuits described in connection with the present disclosure may be implemented or performed with a general purpose processor, a digital signal processor (DSP), an application specific integrated circuit (ASIC), a field programmable gate array (FPGA) or other programmable logic device (PLD), discrete gate or transistor logic, discrete hardware components or any combination thereof designed to perform the functions described herein. A general purpose processor may be a microprocessor, but in the alternative, the processor may be any commercially available processor, controller, microcontroller or state machine. A processor may also be implemented as a combination of computing devices, e.g., a combination of a DSP and a microprocessor, a plurality of microprocessors, one or more microprocessors in conjunction with a DSP core, or any other such configuration.

In one or more aspects, the functions described may be implemented in hardware, software, firmware, or any combination thereof. If implemented in software, the functions may be stored on or transmitted over as one or more instructions or code on a computer-readable medium. Computer-readable media includes both computer storage media and communication media including any medium that facilitates transfer of a computer program from one place to another. A storage media may be any available media that can be accessed by a computer. By way of example, and not limitation, such computer-readable media can comprise RAM, ROM, EEPROM, CD-ROM or other optical disk storage, magnetic disk storage or other magnetic storage devices, or any other medium that

can be used to carry or store desired program code in the form of instructions or data structures and that can be accessed by a computer. Also, any connection is properly termed a computer-readable medium. For example, if the software is transmitted from a website, server, or other remote source using a coaxial cable, fiber optic cable, twisted pair, digital subscriber line (DSL), or wireless technologies such as infrared, radio, and microwave, then the coaxial cable, fiber optic cable, twisted pair, DSL, or wireless technologies such as infrared, radio, and microwave are included in the definition of medium. Disk and disc, as used herein, includes compact disc (CD), laser disc, optical disc, digital versatile disc (DVD), floppy disk and blu-ray disc where disks usually reproduce data magnetically, while discs reproduce data optically with lasers. Thus, in some aspects computer readable medium may comprise non-transitory computer readable medium (e.g., tangible media). In addition, in some aspects computer readable medium may comprise transitory computer readable medium (e.g., a signal). Combinations of the above should also be included within the scope of computer-readable media.

The methods disclosed herein comprise one or more steps or actions for achieving the described method. The method steps and/or actions may be interchanged with one another without departing from the scope of the claims. In other words, unless a specific order of steps or actions is specified, the order and/or use of specific steps and/or actions may be modified without departing from the scope of the claims.

Similarly, the signals described above include one or more fields which may be used in various implementations. The signals may include additional fields, fewer fields, and/or alternative field arrangements without departing from the scope of the claims.

The functions described may be implemented in hardware, software, firmware or any combination thereof. If implemented in software, the functions may be stored as one or more instructions on a computer-readable medium. A storage media may be any available media that can be accessed by a computer. By way of example, and not limitation, such computer-readable media can comprise RAM, ROM, EEPROM, CD-ROM or other optical disk storage, magnetic disk storage or other magnetic storage devices, or any other medium that can be used to carry or store desired program code in the form of instructions or data structures and that can be accessed by a computer. Disk and disc, as used herein, include compact disc (CD), laser disc, optical disc, digital versatile disc (DVD), floppy disk, and Blu-ray® disc where disks usually reproduce data magnetically, while discs reproduce data optically with lasers.

Thus, certain aspects may comprise a computer program product for performing the operations presented herein. For example, such a computer program product may comprise a computer readable medium having instructions stored (and/or encoded) thereon, the instructions being executable by one or more processors to perform the operations described herein. For certain aspects, the computer program product may include packaging material.

Software or instructions may also be transmitted over a transmission medium. For example, if the software is transmitted from a website, server, or other remote source using a coaxial cable, fiber optic cable, twisted pair, digital subscriber line (DSL), or wireless technologies such as infrared, radio, and microwave, then the coaxial cable, fiber optic cable, twisted pair, DSL, or wireless technologies such as infrared, radio, and microwave are included in the definition of transmission medium.

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Further, it should be appreciated that modules and/or other appropriate means for performing the methods and techniques described herein can be downloaded and/or otherwise obtained by an encoding device and/or decoding device as applicable. For example, such a device can be coupled to a server to facilitate the transfer of means for performing the methods described herein. Alternatively, various methods described herein can be provided via storage means (e.g., RAM, ROM, a physical storage medium such as a compact disc (CD) or floppy disk, etc.), such that a user terminal and/or base station can obtain the various methods upon coupling or providing the storage means to the device. Moreover, any other suitable technique for providing the methods and techniques described herein to a device can be utilized.

It is to be understood that the claims are not limited to the precise configuration and components illustrated above. Various modifications, changes and variations may be made in the arrangement, operation and details of the methods and apparatus described above without departing from the scope of the claims.

While the foregoing is directed to aspects of the present disclosure, other and further aspects of the disclosure may be devised without departing from the basic scope thereof, and the scope thereof is determined by the claims that follow.

What is claimed is:

1. A method of determining a transmission rate from a transmitter to a receiver, comprising:

determining, via an electronic device, an amount of data buffered in a network between the transmitter and the receiver;

determining a sustainable throughput of the network based at least in part on a margin of safety; and

determining an update to a transmission rate based at least in part on the sustainable throughput and the amount of data buffered, wherein the update increases the transmission rate in response to determining that a receiving rate of the receiver during a time period exceeds a corresponding transmitting rate of the transmitter during the time period and the update decreases the transmission rate in response to determining that the corresponding transmitting rate exceeds the receiving rate; and transmitting, via the electronic device, a message based on the determined updated transmission rate.

2. The method of claim 1, further comprising adjusting an encoding parameter based at least in part on the transmission rate.

3. The method of claim 1, further comprising transmitting a parameter based on at least one of the amount of data buffered in the network and the sustainable throughput of the network.

4. The method of claim 3, further comprising transmitting the transmission rate.

5. The method of claim 1, further comprising:

correlating transmission and reception rates during a plurality of time periods;

determining the amount of data buffered in the network between the transmitter and the receiver based on an amount a transmission rate exceeded its corresponding reception rate during one or more of the plurality of time periods.

6. The method of claim 5, further comprising determining the sustainable throughput of the network during a particular time period as a percentage less than 100 of an estimated receiver throughput during the particular time period.

7. The method of claim 6, further comprising determining the estimated receiver throughput during the particular time

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period based on an average of reception rates during time periods occurring previous to the particular time period.

8. The method of claim 5, further comprising:

determining a number of contiguous time periods having a transmission rate exceeding its correlated receiving rate; increasing the transmission rate in response to the number of contiguous time periods exceeding a threshold;

determining a second number of contiguous time periods having a reception rate exceeding its correlated transmission rate; and

decreasing the transmission rate in response to the number of contiguous time periods exceeding a second threshold.

9. The method of claim 1, wherein the amount of data buffered in a network is determined based at least in part on a difference between a transmission rate and a network capacity.

10. An apparatus for determining a transmission rate for a transmitter to a receiver, comprising:

a processor configured to:

determine an amount of data buffered in a network between the transmitter and the receiver;

determine a sustainable throughput of the network based at least in part on a margin of safety;

determine an updated transmission rate based at least in part on the sustainable throughput and the amount of data buffered, wherein the update increases the transmission rate in response to determining that a receiving rate of the receiver during a time period exceeds a corresponding transmitting rate of the transmitter during the time period and the update decreases the transmission rate in response to determining that the corresponding transmitting rate exceeds the receiving rate; and

transmit a message based on the determined updated transmission rate.

11. The apparatus of claim 10, wherein the processor is further configured to adjust an encoding parameter based at least in part on the transmission rate.

12. The apparatus of claim 10, further comprising a transmitter configured to transmit a parameter based on at least one of the amount of data buffered in a network and the sustainable throughput of the network.

13. The apparatus of claim 12, wherein the transmitter is further configured to transmit the transmission rate.

14. The apparatus of claim 10, wherein the processor is configured to:

correlate transmission and reception rates during a plurality of time periods;

determine the amount of data buffered in the network between the transmitter and the receiver based on an amount a transmission rate exceeded its corresponding reception rate during one or more of the plurality of time periods.

15. The apparatus of claim 10, wherein the processor is configured to determine the amount of data buffered in a network based at least in part on a difference between a transmission rate and a network capacity.

16. An apparatus for determining a transmission rate of a transmitter to a receiver, comprising:

means for determining an amount of data buffered in a network between the transmitter and a receiver;

means for determining a sustainable throughput of the network based at least in part on a margin of safety;

means for determining an updated transmission rate based at least in part on the sustainable throughput and the amount of data buffered, wherein the update increases

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the transmission rate in response to determining that a receiving rate of the receiver during the time period exceeds a corresponding transmitting rate of the transmitter during the time period and the update decreases the transmission rate in response to determining that the corresponding transmitting rate exceeds the receiving rate; and

means for transmitting a message based on the determined updated transmission rate.

17. The apparatus of claim 16, further comprising means for adjusting an encoding parameter based at least in part on the transmission rate.

18. The apparatus of claim 16, further comprising means for transmitting a parameter based on at least one of the amount of data buffered in the network and the sustainable throughput of the network.

19. The apparatus of claim 16, further comprising means for transmitting the transmission rate to a transmitting node.

20. The apparatus of claim 16, wherein the means for determining an amount of data buffered in the network is configured to correlate transmission and reception rates during a plurality of time periods, and determine the amount of data buffered in the network between the transmitter and the receiver based on an amount a transmission rate exceeded its corresponding reception rate during one or more of the plurality of time periods.

21. The apparatus of claim 16, wherein the amount of data buffered in a network is determined based at least in part on a difference between a transmission rate and a network capacity.

22. A non-transitory, computer readable media storing instructions that when executed, cause a processor to perform a method of determining a transmission rate of a transmitter to a receiver, the method comprising:

determining an amount of data buffered in a network between the transmitter and receiver;

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determining a sustainable throughput of the network based at least in part on a margin of safety;

determining an updated transmission rate based at least in part on the sustainable throughput and the amount of data buffered, wherein the update increases the transmission rate in response to determining that a receiving rate of the receiver during a time period exceeds a corresponding transmitting rate of the transmitter during the time period and the update decreases the transmission rate in response to determining that the corresponding transmitting rate exceeds the receiving rate; and transmitting a message based on the determined updated transmission rate.

23. The non-transitory, computer readable media of claim 22, the method further comprising adjusting an encoding parameter based at least in part on the transmission rate.

24. The non-transitory, computer readable media of claim 22, the method further comprising transmitting a parameter based on at least one of the amount of data buffered in the network and the sustainable throughput of the network.

25. The non-transitory, computer readable media of claim 24, the method further comprising transmitting the transmission rate.

26. The non-transitory computer readable media of claim 22, the method further comprising:

correlating transmission and reception rates during a plurality of time periods;

determining the amount of data buffered in the network between the transmitter and the receiver based on an amount a transmission rate exceeded its corresponding reception rate during one or more of the plurality of time periods.

27. The non-transitory computer readable media of claim 22, wherein the amount of data buffered in a network is determined based at least in part on a difference between a transmission rate and a network capacity.

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